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Prototype Early Warning Fire Detection System: Test Series 2 Results

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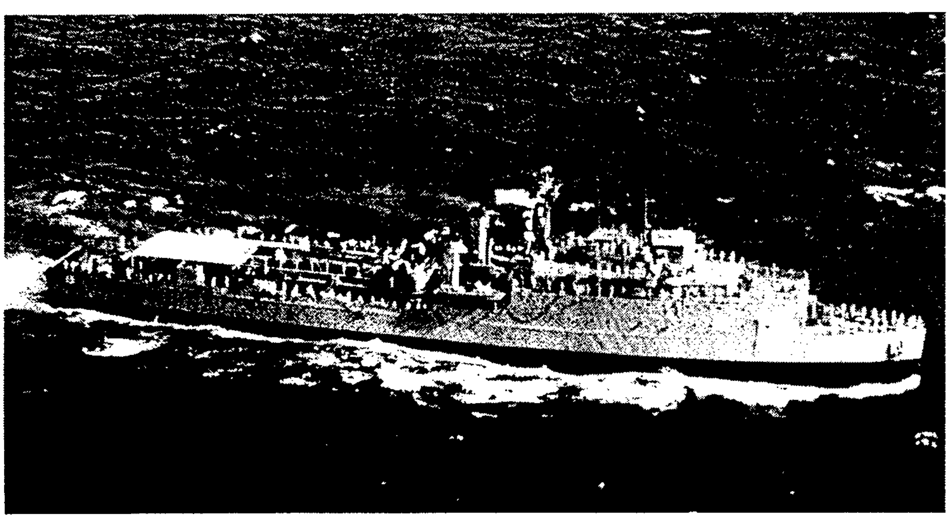

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The system under development combines a multi-criteria (sensor array) approach with sophisticated data analysis methods. Together an array of sensors and a multivariate classification algorithm has the potential to produce an early warning fire detection system with a low nuisance alarm rate. Several sensors measuring different parameters of the environment produce a pattern or response fingerprint for an event. Multivariate data analysis methods can be trained to recognize the pattern of an important event such as a fire. Multivariate classification methods, such as neural networks, rely on the comparison of events (i.e., fires) with non-events (i.e., background and nuisance sources). Variations in the response of sensors can be used to train an algorithm to recognize events when they occur. A key to the success of these methods is the appropriate design of sensor arrays and training sets of data used to develop the algorithm. This test series included a variety of conditions that may be encountered in a real shipboard environment. Every effort was made to consider many representative fire situations and potential interference sources, including the use of Navy approved materials.

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CONTENTS

PROTOTYPE EARLY WARNING FIRE DETECTION SYSTEMS: TEST SERIES 2 RESULTS

1.0 INTRODUCTION

This work is a continuation of a multi-year effort to develop an early-warning fire detection system that is highly immune to nuisance alarms. The work was conducted under the Office of Naval Research (ONR's) sponsored program Damage Control-Automation for Reduced Manning (DC-ARM) as part of a smart system capable of providing automated damage control. Over the past two years, efforts have focused on identifying appropriate sensors and candidate multivariate alarm algorithms [1,2,3,4]. Based on this work, two prototype detection systems (two detectors of each type) were assembled and evaluated in real-time during the Series 1 tests [4] onboard the ex-USS SHADWELL, the Naval Research Laboratory's full scale fire research facility in Mobile, Alabama [5]. Test Series 2 was a continuation of the work of Test Series 1 with an emphasis on providing additional shipboard data to be used for algorithm and prototype optimization. The tests were conducted over the period of April 25 to May 5, 2000.

2.0 BACKGROUND

The system under development combines a multi-criteria (sensor array) approach with sophisticated data analysis methods. Together an array of sensors and a multivariate classification algorithm has the potential to produce an early warning fire detection system with a low nuisance alarm rate. Several sensors measuring different parameters of the environment produce a pattern or response fingerprint for an event. Multivariate data analysis methods can be trained to recognize the pattern of an important event such as a fire. Multivariate classification methods, such as neural networks, rely on the comparison of events (i.e., fires) with nonevents (i.e., background and nuisance sources). Variations in the response of sensors can be used to train an algorithm to recognize events when they occur. A key to the success of these methods is the appropriate design of sensor arrays and training sets of data used to develop the algorithm. This test series included a variety of conditions that may be encountered in a real shipboard environment. Every effort was made to consider many representative fire situations and potential interference sources, including the use of Navy approved materials.

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3.0 OBJECTIVES

The specific objectives of this test series were to:

1. provide a broader range of signature data from real fire and nuisance sources for the purpose of further developing the current prototype detectors and alarm/classification algorithms.
2. evaluate the performance of the prototype detectors with the most current improvement in the alarm algorithms to correctly classify real fire and nuisance sources for further algorithm and prototype optimization,
3. test and evaluate a revised method for executing real-time detection to maintain a constant sampling and processing interval of 2 seconds,
4. evaluate detection performance with respect to detector spacing (i.e., distance from source), and
5. begin to test the selected option of transmitting data to supervisory systems.

The last objective consisted of preliminary trials of transmitting data to remote computers via the fiber optic LAN based Ethernet based on the data transfer protocol described in Appendix B of this report.

4.0 EXPERIMENTAL TESTING

Prototype detection systems were installed in the forward area of the ship on the second deck in the compartments between Frames 15-29. The test area is depicted in Figure 1.

The forward space from Frames 15 to 18 was designated CPO Living Space, the space from Frames 18 to 22 was designated CIC, the starboard space from Frames 22-27 was designated the Operations Office (Ops Office) and the space surrounding the Ops Office was designated the Combat Systems Office (CSO). The CSO was the primary fire compartment in this test series. The source fires/nuisances consisted of those used during previous tests [1,2,4] as well as several new sources. The primary locations of the fire/nuisance sources are also shown in Figure 1 as Location 1, Location 2, and Location 3. The placement of the detectors is indicated in the figure as Location A and Location B.

4.1 Fire Scenarios

This section describes the various fire scenarios selected for testing in this program. A summary table of these scenarios is provided in Table 1. All scenarios were conducted in CSO. Fire scenarios were generally allowed to continue until all detectors in the space reported an alarm status, or had essentially reached a steady state.

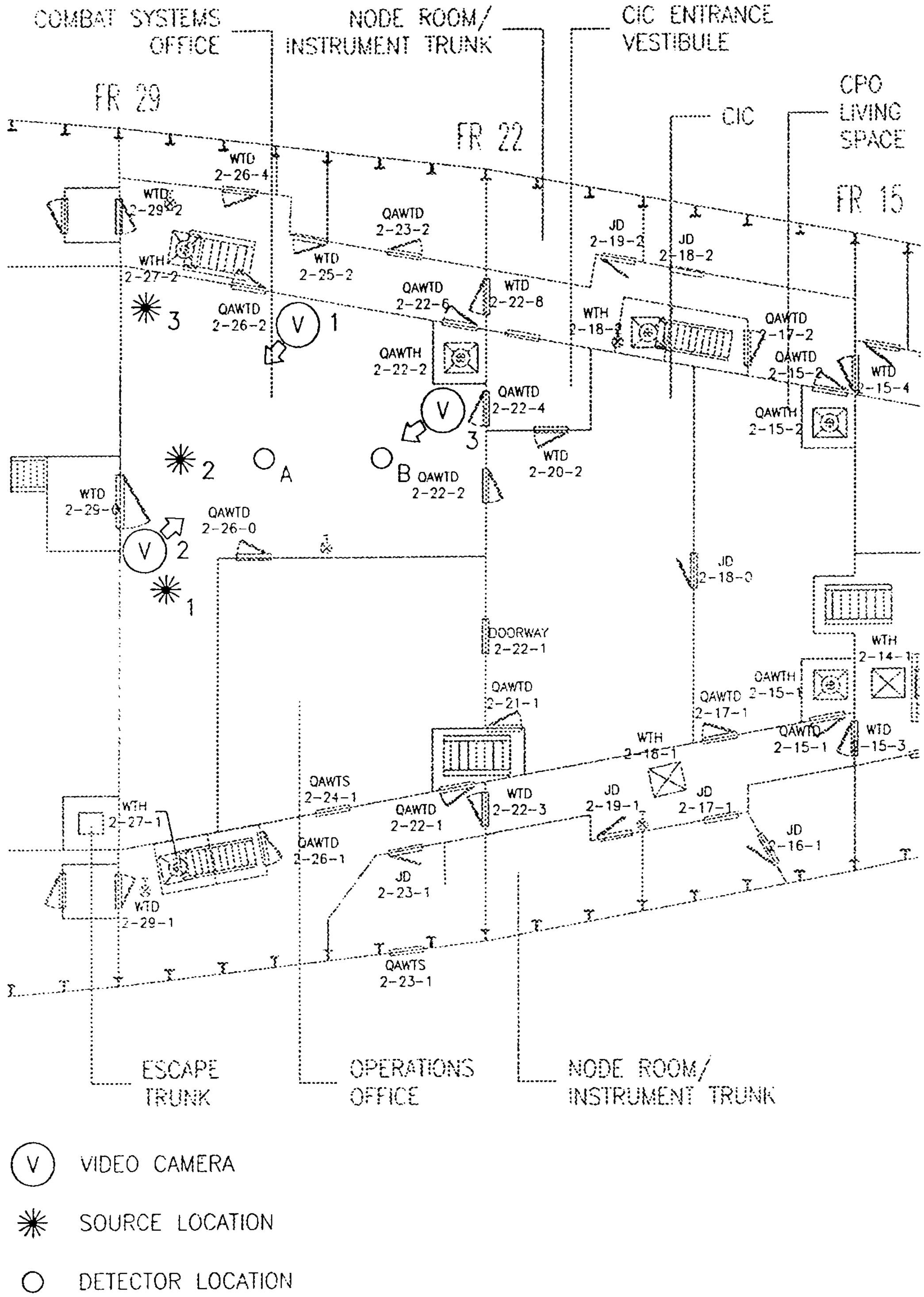

Fig. 1 – Plan view of test area on second deck

Table 1. Summary of Fire Scenarios.

Fire Scenario	*EWFD Tests*	*Description*
F01	038,043,044	Heptane Pool Fire
F02	039	Pipe Insulation Exposed to Fuel Oil Fire
F03	040,070	Flaming Oily Rag and Paper in Small Trash Can
F04	042,083	Smoldering Oily Rag and Paper in Small Trash Can
F05	045	Smoldering Plastic Bag of Mixed Trash
F06	046	Plastic Trash Bag Fire next to TODCO Wallboard
F07	050	Electrical Cables and Pipe Insulation exposed to Laundry Pile Fire
F08	051,085,086,088	Smoldering Electrical Cables (LSDSGU-14)
F09	053,084	Smoldering Bedding Material
F10	054	Flaming Bedding Material
F11	055,056,057,058	Printed Wire Board Fire
F12	059,073	Brief Overheat of a Wire
F13	060,061	BSI 6266 Wire Overheat
F14	071,074,077	Smoldering Electrical Cables (LSTPNW-1½ , MIL C-24643/52-01UN)

4.1.1 Scenario 1 – Heptane Pool Fire

A small heptane pool fire was used as a typical hydrocarbon fuel used in standardized tests as well as in previous tests of this program. Approximately, 260 ml (8.8 fl.oz) of heptane in an 11.4 cm (4.5 in.) diameter pan was ignited with a torch. The bottom of the pan was located 0.4 m (16 in.) above the deck. This test was conducted two times at Source Location 1, and once at Source Location 3.

4.1.2 Scenario 2 – Pipe Insulation Exposed to a Fuel Oil Fire

Calcium silicate insulation with glass cloth lagging pipe insulation was exposed to an F-76 fuel oil fire. The insulation was obtained from Reilly Benton Insulation Co., a Navy supplier. The calcium silicate sample (MIL-I-278) was 5.1 cm (2 in.) internal pipe size and 2.54 cm (1 in.) thick. The glass lagging cloth (MIL-C-20075, Ty CL 3, Reilly Benton Type 300) was applied to the calcium silicate with MIL-A-3316 Class I Grade A adhesive (Vimasco 713).

The insulation was cut in approximately 45 cm (18 in.) long samples and mounted around PVC pipe with corresponding diameters. The lagging was then applied around the insulation per the manufacturer's instruction. After assembly, samples were painted with chlorinated Alkyd White, DOD-E-24607, Color 27880.

The insulation and pipe assembly was exposed to an F-76 flame from 11.4 cm (4.5 in.) diameter fuel pan. The fuel pan contained 260 ml (8.8 fl.oz) of F-76 fuel oil with 20 ml (0.7 fl.oz) of heptane accelerant. The pipe assembly was mounted horizontally, 10 cm (4 in.) above the top of the pan, and bottom of the pan was 0.4 m (16 in.) above the deck. This test was conducted once. The 10-minute post-test background data from this test may have been affected by Coast Guard fire testing on the State of Maine test facility (starboard of the ex-USS Shadwell), as ventilation from the previous test drew smoke generated from the Coast Guard testing from the well deck and through the test space.

4.1.3 Scenario 3 – Flaming Oily Rag and Paper in Small Trashcan

A 6 L (1.6 gal) metal trashcan contained five full sheets of newspaper, two pieces of 0.4 m^2 (4 ft^2) cardboard, and five 0.1 m^2 (1 ft^2) cotton rags saturated with 118 ml (4 fl.oz) of 10W30 motor oil. The cardboard was folded to fit into the trashcan, and the newspaper was folded, slightly crumbled, and placed in the center of the cardboard. The oily rags were between the cardboard and the newspaper. A butane lighter was used to ignite the oily rag both times this scenario was conducted. The bottom of the trashcan was 0.4 m (16 in.) above the deck.

4.1.4 Scenario 4 – Smoldering Oily Rag and Paper in Small Trashcan

A 6 L (1.6 gal) metal trashcan contained five full sheets of newspaper, two pieces of 0.4 m^2 (4 ft^2) cardboard, and five 0.1 m^2 (1 ft^2) cotton rags saturated with 118 ml (4 fl.oz) of 10W30 motor oil. The arrangement of materials in the trashcan was the same as described in the previous scenario. A 2.5 cm (1 in.) diameter hole, 2.5 cm (1 in.) above the bottom of the trashcan, was drilled into the side of the trashcan. A 14.7 cm (5.5 in.) Calrod [Ogden Model MWEJ05J1870, 700Watt, 125Volt] was inserted into the hole of the trashcan. About 90% of the length of the Calrod was allowed to rest on the oily rags. In order to cause smoldering, the Calrod was energized via a variac to 50% of capacity. The bottom of the trashcan was 0.4 m (16 in.) above the deck. This test was conducted twice. In the second test (EWFD_083), no cardboard was used, and the Calrod was initially energized via a variac to 75% of capacity.

4.1.5 Scenario 5 – Smoldering Plastic Bag of Mixed Trash

A plastic trashbag contained various typical waste items, such as paper towels, newspaper, cans, food containers, fruit, and banana peels. The sources were actual trash bags and contents obtained from the crew's mess deck onboard the ship. The dimensions of the bag were 2 m (6.5 ft) in circumference and 0.9 m (3 ft) deep (approximately a 55 gallon bag). The base of the bag was 0.4 m (16 in.) above the deck when placed in a large square metal pan. Exposing the trashbag to a 14.7 cm (5.5 in.) Calrod created this smoldering fire source. The Calrod was leaning at a 45° angle against the trashbag. The variac controlling the Calrod was initially set to 50% of capacity. In this test, the trash was adjusted twice (at ~17 and 24 minutes after initial Calrod initiation) so that it was more in contact with the Calrod. The Calrod was also increased in power to 65% (at 30 minutes after initial Calrod initiation) and then to 75% (at 55

minutes). The bag started to flame at 60 minutes into the test. The Calrod was then removed and the fire extinguished.

4.1.6 Scenario 6 – Flaming Plastic Bag of Mixed Trash Next to TODCO Wallboard

A plastic trashbag as described in Scenario 5 was placed next to the vertically supported wallboard. The trashbag was placed in a pan and ignited at its base with a butane lighter at a spot between the bag and the pan wall. The base of the trashbag was 0.4 m (16 in.) above the deck. This scenario was conducted once.

The white, TODCO Engineering Products, Nomex panel used in this test was a non-filled honeycomb with phenolic resin impregnated fiberglass facing over the aramid fiber honeycomb core. The dimensions of the sheet used were 0.6 m x 0.6 m (2 ft x 2 ft) and the honeycomb was 0.6 cm (0.25 in.) hexagonal MIL SPEC MIL-C-81986, with a density of 48 kg/m^3 (3 lb/ft^3). The overall panel thickness was 1.6 cm (+0.000 cm, - 0.08 cm) (0.625 in. (+0.000 in., -0.030 in.)) thick including the decorative face sheets. The decorative face sheets were high pressure laminate (HPPL) in accordance with MIL SPEC MIL-P-17171, Type IV except that they were 0.07 cm - 0.09 cm (0.027 in. - 0.037 in.) thick. The HPPL was bonded directly to the fiberglass face sheet using the phenolic resin system per MIL SPEC MIL-R-9299, Grade A.

4.1.7 Scenario 7 – Electrical Cables and Pipe Insulation Exposed to a Laundry Pile Fire

Electrical cables and pipe insulation (as described in Scenario 2) were exposed to a laundry pile fire. Four 1 m (39 in.) lengths of LSDSGU-14 cable were vertically supported next to a 0.5 m (19.5 in.) vertical section of insulated pipe. The 9AWG, 2-conductor cable was manufactured by Monroe Cable Co, Military Part No. M24643/15-03UN. The cable consisted of crosslinked polyolefin jacket with silicon rubber insulation on the conductors. The laundry pile consisted of 3 large T-shirts (100% cotton), 3 large briefs (100% cotton, except elastic waistband), 1 extra large button-down short sleeve shirt (65% polyester, 35% cotton), 1 extra large pair of boxer shorts (45% polyester, 55% cotton), and 1 towel (100% cotton). The fire was initiated at the base of the laundry pile, between cable/pipe insulation and the pile. The base of the laundry pile, pipe with insulation, and cables were 0.4 m (16 in.) above the deck.

4.1.8 Scenario 8 – Smoldering Electrical Cables (LSDSGU-14)

This test simulated a long smolder of the LSDSGU-14 cable described in Scenario 7 (length of 33 cm [13 in.]). The jacket and insulation were stripped back on both ends exposing 1.25 cm (0.5 in.) of both conductors. The arc welder was clamped to both conductors on one end of the cable and the other end was grounded to a metal stand via a clamp. The bottom of the vertically supported cable was approximately 6 cm (2.5 in.) above the deck. After initial background data was collected, the arc welder was energized to 375 A. The cables remained energized until the end of the test. The result was the slow heating of the cable that produced light smoke until the insulation broke, causing an increase in smoke production. However, the amount of smoke seemed to cycle with the power of the arc welder, as increasing smoke was

noted with the sound of the welder ramping up its power, and decreasing smoke was noted as the sound of the welder indicated that it was ramping down in power. This test was conducted four times. It was discovered after two of these tests (EWFD_085 and EWFD_086) that the incorrect cable was being used for testing (LSTSGU-4, MZ4643/16-02UN instead of the previously described LSDSGU-14 cable). When exposed to the 375A from the welder, these incorrect cables rapidly heated, melted and smoked. Flames occurred approximately 30 seconds after the cables were energized. The flaming fire only lasted approximately 45 seconds in test EWFD_085 and 10 seconds in test EWFD_086.

4.1.9 Scenario 9 – Smoldering Bedding Materials

A Navy mattress (MIL-M-18351F(SH)) consisting of a 11.4 cm (4.5 in.) thick Safeguard polychloroprene foam core covered with a fire retardant cotton ticking was outfitted with the following items:

1) Two sheets - Federal Specification DDD-S-281,
2) One blanket - Federal Specification MIL-B-844, and
3) One bed spread - Federal Specification DDD-B-151.
4) One mock-up pillow – A Navy feather pillow (Federal Specification V-P-356, Type 4) and a pillowcase (Federal Specification DDD-P-351) were cut and stapled into a 15 cm x 15 cm (6 in. x 6 in.) sample.

Two tests were conducted for this scenario. The first test (EWFD_053) was the same as that conducted in Test Series 1. The composite fuel source was cut into 15 cm x 15 cm (6 in. x 6 in.) squares and layered in the following order (from the bottom up): mattress, sheets, blanket, bed spread, pillow. The smoldering fire source consisted of placing one square sample 1.2 m (4 ft) above the deck, with a 700 W Calrod resting on the center between the bed spread and the pillow. The Calrod was energized with a variac to 50% of capacity, and was allowed to rest on the sample under its own weight, remaining energized for the duration of the test.

For the second test (EWFD_084), the sample was 0.6 m x 0.6 m (2 ft x 2 ft), the bedding was randomly piled on top of the mattress, and the sample was only 0.4 m (16 in.) above the deck. The Calrod was set to 60% power via a variac and placed between the mattress and the bedding. The Calrod was increased to 70% power at 37 minutes after initiation, and then to 80% at 41 minutes after initiation. Flaming ignition of the bedding material subsequently occurred 10 seconds later, and the fire was extinguished after burning for 2 minutes.

4.1.10 Scenario 10 – Flaming Bedding Material

The same bedding sample components from Scenario 9 were used in this test. One sheet of crumpled newspaper placed on top of the pillow was used as the initiating source for this fire. The bottom of the sample was 1.2 m (4 ft) above the deck. A butane lighter was used to ignite the newspaper. The burning newspaper caused the pillow to smolder, which subsequently

caused flaming combustion of the feathers in the pillow. The fire burned for just over 2 minutes, at which point it smoldered for a minute and then stopped burning.

4.1.11 Scenario 11 – Printed Wire Board Fire

Internal PWB failures are also a fairly common event in electronic equipment. These are generally caused by contaminates within the PWB, a by-product of the manufacturing process, but can also be induced by component failures and/or power surges. In reference [6], a printed wiring board (PWB) test was specially designed to replicate fires in circuit boards. The test board was fabricated with two parallel 50 mil wide tracks, spaced 50 mil apart. The tracks extended to one end of the 41-cm long board where solder coated pads were provided to connect the circuit to the power supply. At the opposite end of the 38 cm long tracks, a 10 mil wide track bridged the long tracks to complete the circuit and provide a short length of higher resistance track where localized heating could develop and in time lead to the formation of an arc. The test board was fabricated of FR-4 substrate material, and the board was coated with dry film solder mask, materials typical of those used in telecommunications equipment manufacture.

The overheated power tracks, aligned parallel to one another, pyrolyze or carbonize the substrate material between them. After a time, the insulating properties of the material are sufficiently degraded that an arc develops between the two tracks, igniting the gaseous pyrolosis products. A flame about ½ inch tall results, and travels along the tracks with the progressing arc. The process is self-sustaining as long as power is applied to the circuit. The arc travels along the tracks starting at the point of ignition and moves closer to the connecting pads at the end of the PWB.

The test PWB was mounted vertically in a stand (1.2 m (4 ft) above the deck) with the tracks aligned parallel to the deck, and connected to the leads of a Kenwood model PD18-3AD regulated DC power supply. The tests were conducted with the regulated DC power supply set to deliver a constant current of 8.5 A with a peak voltage setting of 6.0 V. The test PWB was mounted between two non-energized PWB's to help channel the smoke upwards. This test was conducted four times sequentially. After the first test (EWFD_055), a fire curtain was hung to cover the entrance to the alcove area on the starboard side of CSO. This was done to prevent smoke entry into this area. After the second test, the positions of prototypes 1A and 2A were swapped to determine if a sensor problem existed. After the third test, prototypes 1B and 2B were also moved to location A.

Note that consistency in board manufacturing, and possibly the contact between the power leads and the PWB circuit, appeared to affect the preheat time of the boards. The time needed to heat up the board from initiating the power source to arcing of the circuit varied from test to test. The time recorded between initial energizing and the first appearance of smoke (precursor to arcing) was 531 seconds, 565 seconds, 128 seconds, and 85 seconds, respectively for tests EWFD_055, EWFD_056, EWFD_057, and EWFD_058.

4.1.12 Scenario 12 – Brief Overheat of a Wire

This source consisted of temporarily overheating a 24 AWG PVC wire energized at 28 amps, 20 V for 30 seconds. This test was intended to represent a transient burn out of an electrical component. Though a transient event, the effluent from this source is the same as a case in which the event is the early stages of a longer, developing electrically energized cable fire. The wire was NORDCOM/CDT's RZ distributing frame wire, consisting of a single 0.7 mm (0.178 in.) diameter strand insulated with PVC to a radial thickness of 1.0 mm (0.041 in.). The wire was wrapped around an inert strip of marinite board approximately 1.5 m (5 ft) above the deck. The wire was energized using a Kenwood model PD18-3AD regulated DC power supply and 10 AWG stranded wire leads, 3.25 m (10.66 ft) long between the wire sample and the power supply. This test was conducted twice. In the first test (EWFD_059), three wires were overheated sequentially at Source Location 3, and two were overheated at source location 2. In the second test (EWFD_073), only one wire was overheated at Source Location 2.

4.1.13 Scenario 13 – BSI 6266 Wire Overheat

British Standards Institute standard BS 6266, *"Code of Practice for Fire Protection for Electronic Data Processing Installations"* [7] details five test methods for testing smoke detection systems in electronic data processing facilities. These tests are intended to replicate the types and/or quantities of smoke produced in the early stages of a fire in a telecommunications or data processing facility. One of these tests is intended to represent a potential electrical fire via ohmically heating a sample of wire. The wire used is specified by the standard to be constructed of 10, 0.1 mm strands, insulated with PVC to a radial thickness of 0.3 mm, with a cross-sectional area of 0.078 mm^2. The wire was obtained from Vision Systems, UK.

Two 1 m long wires (BSI 6266 spec) were heated at 6 V (28 A) for 60 seconds using the Kenwood power supply described in Scenario 12. The BSI 6266 wire was wrapped around an inert strip of marinite board using the same fixture as in Scenario 12, supported approximately 1.5 m (5 ft) above the deck. This test was conducted twice.

4.1.14 Scenario 14 – Smoldering Electrical Cables (LSTPNW-1½)

This source represented an early stage electrical fire. The setup consisted of energizing several cables of a larger bundle to induce a smoldering Class C fire. The wire used (Monroe Cable Co., LSTPNW-1 ½, MIL C-24643/52-01UN) was a 22 AWG, 3 conductor cable with a crosslinked polyolefin jacket and crosslinked polyethylene insulation. Ten cables were bundled together in these tests. The jacket and insulation were stripped back on both ends exposing 1.25 cm (0.5 in.) of the conductors. The arc welder was clamped to the conductors on one end of the cable and the other end of the cables was grounded to a metal stand via a clamp. The bottom of the vertically supported cable was approximately 5.7 cm (2.3 in.) above the deck. The cables remained energized for the entire test period. The result was the slow heating of the cable that produced light smoke until the insulation broke, causing the smoke to become heavier. This test

was conducted three times. In the first test (EWFD_071), the welder was set to 250 A, 50% power, and all 10 cables (30 conductors) were connected to the arc welder. After ten minutes of energizing the cable, the welder was increased to 60%, then 70% after an additional 5 minutes. Finally, the welder was increased to 80% and 100% in three-minute intervals. This test did not generate much smoke or any alarms for either the Simplex COTS detectors or the EWFD prototypes. Therefore, in the last two tests (EWFD_074 and EWFD_077), the welder was set to 375 A, 100% power for the duration of the tests. Additionally, only 5 cables (15 conductors) were connected to the arc welder. These tests produced more smoke and alarms on both detection systems.

4.2 Nuisance Scenarios

This section describes the various nuisance scenarios selected for testing in this program. A summary table of these scenarios is provided in Table 2. All of these scenarios were conducted in the CSO. Most sources were located at Source Location 2. A number of the sources did not cause smoke detectors to reach alarm levels despite moving the sources closer and exceeding extreme exposures. For example, sweeping flour was done to the point of having a visibly dense cloud of dust within the space and surrounding the detectors. It is highly unlikely that an actual event would have created more airborne particulate than that observed.

Table 2. Summary of Nuisance Scenarios.

Nuisance Scenario	*EWFD Tests*	*Description*
N01	041,065	Toasting Pop Tarts™
N02	052	Welding Steel
N03	048,049	Cutting Steel with acetylene torch
N04	047	Burning popcorn
N05	068,087	Cigarette smoke
N06	066,067	Normal Toasting
N07	067	Grinding Steel
N08	063	Aerosol Deodorants
N09	064	Sweeping up a dropped bag of flour
N10	075,076,081,082	Steam generation.
N11	062,072,080	Cooking oil

4.2.1 Scenario 1 – Toasting Pop Tarts

In test EWFD_041, one four-slice toaster (Toastmaster Model D165, 120 V, 50-60 Hz, 1700W) was filled with chocolate frosted Pop Tarts™ and set to "dark". The first four Pop Tarts™ were toasted for 235 seconds, and then four new ones were immediately started (toasted for 173 seconds). In the second test (EWFD_065), 8 Pop Tarts™ were toasted at once using two toasters. These Pop Tarts™ were allowed to blacken, toasting for 252 seconds (starboard toaster)

and 270 seconds (port toaster). The bottom of the toasters was 1.2 m (4 ft) above the deck in both tests. This source was used to produce a different type of cooking effluent than previously obtained with toast. It was expected that the higher fat content (i.e., the frosting) would yield a different size and density particle distribution.

4.2.2 Scenario 2 –Welding Steel

Welding and other hot work are typical maintenance activities that can occur onboard a ship. Welding of steel was conducted in the compartment 0.4 m (16 in.) above the deck. The arc welding consisted of running a weld across a 0.6 cm (0.25 in.) thick steel plate using a 0.32 cm (0.125 in.) number 7018 rod and a constant current setting of 100 A. A total of 14 rods were used during the 19-minute exposure time for this test.

4.2.3 Scenario 3 – Steel Cutting

An oxy-acetylene torch was used to cut a 0.32 cm (0.125 in.) thick steel plate, 0.4 m (16 in.) above the deck. Cutting occurred in a continuous fashion by cutting off 5 cm (2 in.) wide strips of steel from the plate. The cut strips varied in length, as the plate was not a regular rectangle. In both tests where cutting was performed, cutting was essentially continuous for about 25 minutes in the first test and 27 minutes in the second test. The only difference in the two tests conducted was the condition of QAWTD 2-22-2. This fitting was open during the first test (EWFD_048) and closed during the second test (EWFD_049).

4.2.4 Scenario 4 – Burning Popcorn

A typical bag of microwave popcorn (ACT II, Butter Lovers, 3.5 oz bag) was cooked on high in an 850 W microwave oven (a Tappan Model TMT1046150) for 12 minutes. The bottom of the microwave was 1.2 m (4 ft) above the deck. By the end of the 12-minute period, the popcorn was a black mass of char.

4.2.5 Scenario 5 – Cigarette Smoke

Although smoking is prohibited inside Navy ships, it still remains a very plausible nuisance source. This test consisted of four people smoking cigarettes/cigars in the test compartment, where each person smoked 3 to 4 cigarettes (Camel Filters, Marlboro Lights, Salem Menthols and Doral Menthols for the first test, Black 'n' Mild cigars and Newports for the second test). In the first smoking test (EWFD_068), four people smoked a total of 15 cigarettes in 19 minutes. The smokers were standing at Location 2, approximately 1 m aft of the detectors. In the second test (EWFD_087), a total of 2 cigars and 3 cigarettes were smoked in 11 minutes. The smokers were standing directly under the location A sensors during this test. Even with the smokers directly below the detectors, the smoke exposure to all of the detectors appeared to be quite uniform as the smoke diffused and spread as it rose approximately 1.5 m (4.9 ft) to the overhead.

4.2.6 Scenario 6 – Normal Toasting

In these tests, two four-slice toasters (Toastmaster Model D165, 120 V, 50-60 Hz, 1700 W) were filled with white bread and set to "dark". Eight slices of bread were toasted at a time resulting in very dark toast, however none of the slices were burnt in these tests. Two batches of bread were successively toasted, yielding 16 total slices for each test. During the first test (EWFD_066), power to the CSO was lost (due to a tripped fuse) at approximately 250 seconds into the second toasting cycle. The photoelectric and ionization detectors on prototype 1A were switched for the second test (EWFD_067). It was discovered after this test that these new detectors were not working properly (i.e., not outputting the correct voltage), so they were switched back before the next test. Consequently, the results for EWFD 1A in test 67 are invalid. Also in test EWFD_067, the data acquisition system remained on after the ventilation period and, thus, collected spurious data beyond 1430 seconds after initiation. All data after this point should be disregarded. The bottom of the toasters was 1.2 m (4 ft) above the deck for both tests.

4.2.7 Scenario 7 – Grinding Steel

A handheld grinder was used to grind a rusty steel plate in this test. The grinder used was a Black and Decker 4.5in Angle Grinder, Model 2750G, with an 11 cm (4.5 in.) diameter, 0.6 cm (0.25 in.) thick Norton General-Purpose Mini Disc grinding pad. The grinding took place approximately 0.4 m (16 in.) above the deck. Grinding was conducted for 16 minutes, resulting in a cloud of dust.

4.2.8 Scenario 8 – Aerosol Deodorants and Hairspray

An aerosol deodorant (Suave 'Shower Fresh' anti-perspirant and deodorant by Helene Curtis) and hairspray (Rave '4 – Mega Hold' by Chesebrough-Ponds) were used in a manner to simulate use by multiple people over a short period of time as may occur in a washroom or crew living space. In this test, four cans of aerosol (two of each type) were discharged from the aft bulkhead (aft of Location 2), 1.8 m (5.9 ft) above the deck. The cloud of aerosol was directed toward the detector at Location A resulting in a dense cloud surrounding the units for a period of approximately 210 seconds. It is highly unlikely, that detectors would be exposed to a higher concentration on board an active ship than the conditions evaluated in this scenario.

4.2.9 Scenario 9 – Spilled Flour Sweeping

In this test, a bag of flour was dumped at Source Location 3 and swept around the deck using brooms to create a very dusty compartment. The flour was vigorously swept up, moving from source location 3 towards the center of the room and Source Location 2. The flour was swept around and fanned with cardboard for about 10 minutes during this test, creating a large dust cloud in the space. It is highly unlikely that an actual event would have created more airborne particulate than that observed.

4.2.10 Scenario 10 – Steam Generation

This scenario was intended to represent the cleaning of hot griddles in a galley or possibly the flow of water vapor from a washroom. Water was slowly poured into a hot skillet or pan to create multiple flashes of hot steam. This test was conducted three times, twice using a 6" cast iron skillet (made by Lodge), and once using a large steel pan (~0.45 m x 0.45 m (18 in x 18 in.)). A portable two-burner propane stove (Model # 0711 by Ozark Trail) with Coleman propane was used in test EWFD_075 (set on high) to heat the skillet. Water was slowly poured into the skillet and allowed to completely boil away. After about eight minutes more water was added, however the pan was not hot enough to generate significant amounts of steam. In the second test (EWFD_076), the skillet was heated with a torch until it was red hot. Water was added only once during this test, and it boiled away in approximately 2 minutes. In the final test, the large steel pan was heated with a torch until it was red hot. The objective in this test was to create a larger mass of hot metal in order to create more steam than in the previous tests. Water was added in small splashes for about 4 minutes, and then the pan was removed and a larger area of the pan base reheated. Water was again added in small splashes for about 3 minutes. This test covers two data files (EWFD_081 and EWFD_082), where the break was used to reheat the pan. The source was located approximately 1.2m (4ft) above the deck in the first test, and 0.4 m (16 in.) above the deck in the other tests.

4.2.11 Scenario 11 – Cooking Oil

The purpose of this nuisance scenario was to simulate the vaporization of oil or grease in a galley. This test was conducted three times. For the first test (EWFD_062), an electric wok (1600W "Nutritionist" High Performance Electric Wok, model no. EW5 by Salton/Maxim Housewares, Inc.) was set on high and allowed to heat up. A large tablespoon full of shortening (partially hydrogenated soybean oil with citric acid) was added to the wok to produce vapor. Only a small amount of vapor was created, so over time, the shortening was stirred, partially removed from the wok, and then water added in attempts to increase the amount of vapor created. The result after 25 minutes was a light haze in the center of the compartment. The propane stove and cast iron skillet described in scenario 10 were used in for the remaining tests in an attempt to achieve hotter cooking temperatures. In the second test (EWFD_072) two teaspoons of vegetable oil (100% vegetable oil, "Lou Ana" made by Ventura Foods, LLC.) were added to the skillet, which was heated by the propane stove on high. Another teaspoon of vegetable oil was added about 3½ minutes after the burner was first initiated. This test generated much more smoke than the first test with the wok and shortening. The third test (EWFD_080) was identical to the second test. In all tests, the wok/skillet was located 1.2 m (4 ft) above the deck.

4.3 Sensor Calibration Tests

Sensor calibration checks were performed at the beginning and the middle of this test series for the carbon monoxide, oxygen, and hydrocarbon sensors. These sensors were tested

using standard calibration gases with 50 ppm concentrations for carbon monoxide and 20 ppm for ethylene (hydrocarbon) sensors, and 100% nitrogen for testing the oxygen sensor. The general procedure was to collect several minutes of background data and then to pass the calibration gas over the sensor at a rate of 300 to 500 ml/min until the sensor reading stabilized. Although no calibration gases were available for nitric oxide and hydrogen sulfide, their ambient readings were adjusted to zero. The relative humidity sensors were also checked using a hand-held sling psychrometer and adjusted during the pre-testing calibration. They were checked again during the middle-of-test calibration tests.

In comparing the pre-testing calibration tests with the middle-of-test calibration tests, it is evident that the CO and O_2 sensors were generally stable, with little drift in the measurements. Table 3 summarizes the calibration experiments. The only potential drift occurred in the hydrocarbon sensor, which changed by +2.5 ppm (ambient) from the pre-test to the middle-of-test calibration check. The hydrocarbon sensor appeared to malfunction sometime between the calibration tests based on the reading of the hydrocarbon sensor in the second calibration test. The calibration gas used in both calibration tests was 20 ppm. In the pre-testing calibration of this sensor, it's output was adjusted to read approximately 20 ppm, however the sensor reading was a maximum value of 50.5 ppm when it was exposed to the calibration gas in the second test.

5.0 EXPERIMENTAL SETUP

5.1 Test Area and Closures

The test area for this series was FR 15 to 29 on the second deck (Figures 1 and 2). This test area consisted of four spaces. The forward space from FR15 to 18 was designated CPO Living Space, the space from FR18 to 22 was designated CIC, the starboard space from FR22 to 27 was designated as the Operations Office (Ops Office), and the surrounding space to the Ops Office was designated the Combat Systems Office (CSO). All fire/nuisance sources were located in the Combat Systems Office. Three source locations were used in this test series, as indicated in Figure 1. Initially only Source Locations 1 and 2 were designated for the test series. However, Source Location 3 was added after test EWFD_043. During the initial tests (before EWFD_043) utilizing Source Location 1 it was observed that the majority of the smoke generated by the fire sources was moving into the starboard alcove area of the CSO before flowing into the remainder of the compartment. This smoke movement pattern in combinationwith the small incipient nature of some of the sources resulted in low detection rates by either the prototype or COTS systems. In order to concentrate on producing measurable fire signatures, the majority of the fire sources were moved to Source Location 3. Additionally, a fire curtain was installed over the entrance to the starboard alcove of CSO after test EWFD_055 to further prevent any smoke migration to this area (indicated in Figure 2).

Two major ducts were present in CSO at the time of testing, and are shown in Figure 2 Both ducts were approximately 0.46 m (18 in.) in width and 0.53 m (21 in.) below the overhead. Each duct was 0.48 m (19 in.) deep, although duct #2 had some variation. The aft portion of

Table 3. Summary of Sensor Calibration Tests.

	Calibration Gas Concentration	*Pre-Testing Calibration*			*Middle-of-Testing Calibration*		
		Ambient Reading (ppm)	Stabilized Reading (ppm)	Reaction time (sec) [ambient to stabilized]	Ambient Reading (ppm)	Stabilized Reading (ppm)	Reaction time (sec) [ambient to stabilized]
EWFD1A – CO	50 ppm	-0.06	50.4	40	-0.29	50.5	31
EWFD2A – CO	50 ppm	-0.16	50.4	90	-0.17	51.6	102
EWFD1B – CO	50 ppm	0.04	50.4	100	-0.55	50.5	50
EWFD2B – CO	50 ppm	-0.06	50.1	92	-0.30	49.8	47
Oxygen	100% Nitrogen	21.3 (%)	0.0 (%)	45	21.2 (%)	0.0 (%)	37
Hydrocarbon	20 ppm	0.1	20.7	504	2.6	50.5	130

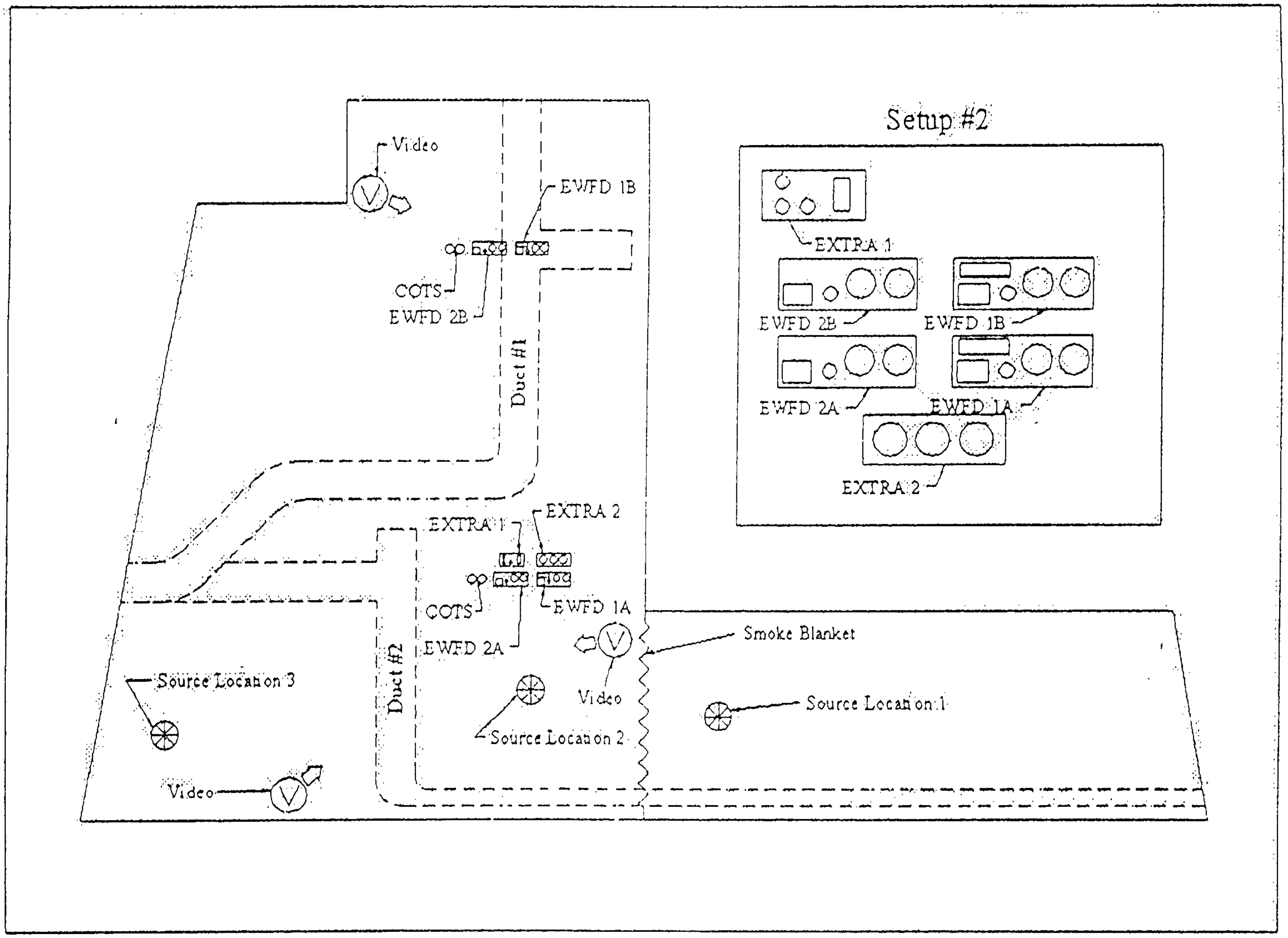

Fig.2 – Location in the combat systems office.

duct #2 was only 0.23 m (9 in.) wide. The ducts had a noticeable effect on the flow of the low momentum smoke from the sources, particularly those at Location 3. The ducts generally appeared to block and impede the flow of smoke. In some cases, smoke appeared to flow below the ducts before passing over the ducts along the overhead.

All perimeter doors and scuttles were closed to the test area during each test. The following closure plan was used to allow ventilation between compartments in the test area:

Fittings that were open:

1.	QAWTD	2-17-1
2.	JD	2-18-0
3.	Doorway	2-22-1
4.	QAWTD	2-22-4
5.	QAWTD	2-26-0

Fittings that were closed:

1.	QAWTH	2-15-1
2.	QAWTH	2-15-2
3.	WTD	2-20-2
4.	QAWTD	2-21-1
5.	QAWTD	2-22-2
6.	QAWTS	2-24-1
7.	QAWTD	2-26-2
8.	WTD	2-29-0

The ventilation in the space consisted of the Total Protection Exhaust System (TPES) drawing air through two exhaust ducts located within the Engineering Office, which is located between FR20 and FR22 on the port side of CIC. Supply air was provided through the open fittings in the test area. The general flow pattern was from the starboard passageway through CPO, CIC, Ops Office, and across the CSO test space. The measured airflow rates at the opening of the two TPES ducts were 319 cfm and 112 cfm. The combined air flow rate of 431 cfm effectively produced five air changes per hour in the CSO, which has an open volume of approximately 144 m^3 (5100 ft^3). This ventilation is representative of the 4 to 5 air changes per hour that is typically found on Navy ships [8].

5.2 Prototype Fire Detection System

The same two prototype fire detection system configurations used in Test Series 1 [4] were evaluated in this series. The detection system consisted of a group of sensors, a data acquisition system and a desktop computer used to implement the alarm algorithm (PNN)

processing, data storage, and display. The details of the two prototype detectors and the data acquisition system are discussed in the following sections.

5.2.1 Sensors

The primary differences in the two prototype detectors was the group of sensors, and consequently, the probabilistic neural network (PNN) alarm algorithm, which was based on the sensors used [1]. The PNN used in this test series was an updated version from that used in Test Series 1 [4]. Table 4 shows the sensor details for each of the prototypes. The sensors of a detector were mounted together as a single assembly, as shown in Figure 3. The sensors were mounted on a steel chassis that encased a power supply and much of the wiring. The chassis was also designed with mounting flanges to fasten it to the overhead and hinges on one side to allow interior access while the prototypes were mounted to the overhead. Four System Sensor ionization and four photoelectric detectors were used in the four prototypes. System Sensor provided correlations (based on UL 268 smoke box data) to convert the sensor outputs to engineering units. The conversions used are listed in Table 5. The ionization ΔMIC (picoamperes) value was converted to percent obscuration per meter using a second general correlation from System Sensor data obtained from UL 268 smoke box tests (see Appendix D). The main System Sensor ionization detector used on prototype 1A (#7) showed dramatically different performance from the other ionization detectors installed on the other prototypes. Specifically this detector was found to be much more sensitive to the smoke and particulate generated in the test scenarios.

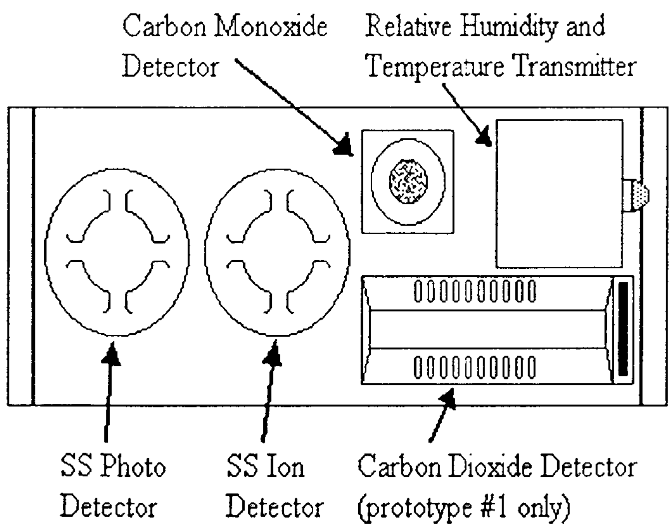

Fig. 3 – Physical layout of sensors when mounted on chassis.

Table 4. Details of Prototype Fire Detectors.

No.	*Species*	*Sensor Range*	*Resolution*	*Instrument Model No.*	*Manufacturer*
Prototype No. 1 (EWFD1)					
1	Ionization smoke detector	d MIC ~ 40		1251 with base no. B501	System Sensor
2	Photoelectric smoke detector	0.052-12.5 %/m (0.016 - 4 %/ft)	0.052 %/m (0.016 %/ft)	2251 with base no. B501	System Sensor
3	Carbon monoxide ($CO_{50\ ppm}$)	0-50 ppm	0.5 ppm	TB7E-1A	City Technology
4	Relative humidity (RH)	3-95%	±2% RH accuracy	HX93V transmitter	Omega
5	Carbon dioxide (CO_2)	0-5000 ppm	Accuracy= greater of ±5% of reading or ±100 ppm	2001V	Telaire/Engelhard
Prototype No. 2 (EWFD2)					
1	Ionization smoke detector	d MIC ~ 40		1251 with base no. B501	System Sensor
2	Photoelectric smoke detector	0.052-12.5 %/m (0.016 - 4 %/ft)	0.052 %/m (0.016 %/ft)	2251 with base no. B501	System Sensor
3	Carbon monoxide ($CO_{100\ ppm}$)	0-100 ppm	0.5 ppm	TB7F-1A	City Technology
4	Relative humidity (RH)	3-95%	±2% RH accuracy	HX93C transmitter	Omega
5	Temperature (Temp Omega)	-20C to 75C	±0.6°C accuracy	HX93C transmitter (RTD)	Omega

Table 5. Conversions of System Sensor Detectors Used in the Prototypes

Detector Type	*EWFD Tests*	*Prototype*	*Conversion*
Ionization 6	067	1A	$\Delta MIC = \Delta V * 50$
Ionization 7	All except 067	1A	$\Delta MIC = \Delta V * 50$
Photoelectric 1	067	1A	$\%/ft = \Delta V * 2.7$
Photoelectric 8	All except 067	1A	$\%/ft = \Delta V * 4.0$
Ionization 4	038 to 045	2A	$\Delta MIC = \Delta V * 47$
Ionization 5	046 to 088	2A	$\Delta MIC = \Delta V * 50$
Photoelectric 4	All	2A	$\%/ft = \Delta V * 3.0$
Ionization 2	All	1B	$\Delta MIC = \Delta V * 50$
Photoelectric 2	All	1B	$\%/ft = \Delta V * 2.5$
Ionization 3	All	2B	$\Delta MIC = \Delta V * 50$
Photoelectric 3	All	2B	$\%/ft = \Delta V * 2.4$

5.2.2 Data Acquisition and Processing

Each sensor was hard-wired to the data acquisition system, which was located in the starboard side Node Room (see Figure 1). The data acquisition system consisted of National Instruments hardware (SCXI 1001 Chassis, SCXI 1100 modules, and SCXI 1303 Terminal Blocks) controlled via LabVIEW 5.1 full development software. The data acquisition system was operated using a Dual Pentium 200 MHz PC computer running Windows NT (128 MB RAM). The LabVIEW software was used to develop a data acquisition controller that could acquire data and execute the PNN alarm algorithm in real time, save the data, display the data, and send the data to a computer in the Control Room via the fiber optic Ethernet. This software was also updated for this test series to include the ability to transfer data to supervisory control groups via TCP/IP or shared file access. The PNN software was written using MATLAB (which can interface with LabVIEW) and the data was transmitted to the Control Room using the software package DataSocket (provided with LabVIEW). During tests, the data acquisition/processing system was synchronized in time with the COTS Simplex smoke detection system currently installed on the ship. A more detailed explanation of the data acquisition system can be found in Appendix A, and an explanation of the format of the data available to the supervisory control groups is provided in Appendix B

5.2.3 Detector Locations

The two prototype detectors (Table 4) were co-located with the COTS system (Simplex photo and ion) in the Combat System Office, Locations A and B. Figure 2 shows the locations of the detectors in the test area. The detectors at Location A were intented to be the primary fire detectors with the second set of detectors (Location B) providing additional information on detector sensitivity with respect to distance between the source and the detector. The "extra sensors" indicated in the figure are described in the next section. The exact locations of the detector groups are indicated in Table 6 and a visual indication is provided in Figure 2. Two primary setups were used during this test series. The first setup (from tests EWFD_038 to EWFD_057) used prototype units positioned at locations A and B. For the second setup (from tests EWFD_058 to EWFD_088), all the prototypes were positioned at location A. Prototypes 1A and 2A were in the exact same position as before with the remainder of the detectors set up as indicated by "Setup #2" in Figure 2. This switch was made to investigate sensor functionality and repeatability. After test EWFD_082, prototype 2B was moved back to its original position at location B. For test EWFD_057, the position of prototypes 1A and 2A were switched to determine if a small change in position would have an effect on source detection. These detectors were returned to their original positions after this test.

Table 6. Locations in CSO (measured from aft, port corner of CSO to the center of each array).

Detector Group	*Distance forward (m [ft])*	*Distance starboard (m [ft])*	*Radial Distance from Source Location 1 (m [ft])*	*Radial Distance from Source Location 2 (m [ft])*	*Radial Distance from Source Location 3 (m [ft])*
Simplex COTS Detectors					
Simplex COTS at Location A	4.5 (15)	2.8 (9)	3.5 (12)	1.4 (5)	3.9 (15)
Simplex COTS at Location B	4.6 (15)	6.6 (22)	6.2 (21)	5.1 (17)	6.6 (22)
Setup #1					
EWFD 1A	5.2 (17)	2.8 (9)	2.9 (10)	1.3 (4)	4.5 (15)
EWFD 2A	4.7 (15)	2.8 (9)	3.4 (11)	1.3 (4)	4.1 (13)
EWFD 1B	5.3 (17)	6.6 (22)	5.9 (19)	5.1 (17)	7.0 (23)
EWFD 2B	4.8 (16)	6.6 (22)	6.1 (20)	5.1 (17)	6.7 (22)
Extra 1	4.7 (15)	3.0 (10)	3.5 (11)	1.6 (5)	4.2 (14)
Extra 2 (w/ SAM Detect)	5.2 (17)	3.0 (10)	3.0 (10)	1.5 (5)	4.6 (15)
Setup #2					
EWFD 1A	5.2 (17)	2.8 (9)	2.9 (10)	1.3 (4)	4.5 (15)
EWFD 2A	4.7 (15)	2.8 (9)	3.4 (11)	1.3 (4)	4.1 (13)
EWFD 1B	5.2 (17)	3.0 (10)	3.0 (10)	1.5 (5)	4.6 (15)
EWFD 2B	4.7 (15)	3.0 (10)	3.5 (11)	1.6 (5)	4.2 (14)
Extra 1	4.6 (15)	3.2 (11)	3.7 (12)	1.8 (6)	4.2 (14)
Extra 2 (w/ SAM Detect)	5.0 (16)	2.6 (8)	3.0 (10)	1.1 (4)	4.0 (14)
Source Locations					
1	1.2 (4)	7.6 (25)	-	-	-
2	1.5 (5)	4.9 (16)	-	-	-
3	1.0 (3)	1.0 (3)	-	-	-

Notes:

- All locations represent the approximate center of each group of detectors.

5.3 Additional Instrumentation

The performance of the prototype fire detectors was compared to the performance of the conventional ionization and photoelectric smoke detectors currently installed onboard ship (COTS Simplex system). The shipboard system consisted of Simplex ionization detectors (Model 4098-9717) and Simplex photoelectric detectors (Model 4098-9714) monitored with a single alarm panel (Simplex Model 4020). This fire alarm system provided time of alarm data for the exposed detectors. Additionally, the alarm verification feature was enabled for these detectors so that performance could be evaluated based on the goal of minimizing nuisance alarms. The alarm sensitivity of these detectors was set to 8%/m (2.5%/ft) for photoelectric and 4.2 %/m (1.3 %/ft) for ionization, which have been the settings of operation since installation.

Three thermocouples were positioned in the Ops Office to monitor overhead temperatures. Thermocouples were mounted at each of the Detector Locations (A & B), as noted on Figures 1 and 2, to measure the air temperature near the prototypes. The third thermocouple was mounted on the overhead to monitor the temperature over the primary source location (1 or 3).

RST (Daimler Chrysler) provided a SAM Detector™ multi-sensor detector with alarm algorithm. A laptop with RS-232 (serial port) capabilities was used to monitor and save the output data from the SAM Detector using the software DirectWare 2.01 provided by RST. The device was mounted on a board with a hydrocarbon sensor and a residential smoke detector, indicated by "EXTRA 2" in Figure 2.

Additional sensors were included for data collection and future algorithm development. These sensors included oxygen, hydrogen sulfide, nitric oxide, hydrocarbon, residential ionization smoke detector and the same model residential ionization smoke detector with the cover and bug screen removed. The hydrocarbon sensor and standard residential smoke detector were mounted on a wood board with the SAM Detector™. The remainder of the sensors were located on a chassis similar to the prototype chassis and mounted on the overhead in the position indicated by "EXTRA 1" in Figure 2. Table 7 summarizes the additional sensors used in these tests.

Three video cameras were installed as shown in Figures 1 and 2. The cameras were installed with extra cable so that they could be moved around the space when necessary. Camera 1 was positioned to view the smoke development from the source and spread across the overhead toward the detectors. Cameras 2 and 3 were used primarily for viewing the spread of smoke in the overhead at the locations of the detectors. Figure 1 is indicative of the camera positions prior to the use of Source Location 3, and Figure 2 indicates the camera positions after the switch from Source Location 1 to Source Location 3 (EWFD_043).

Table 7. Additional Sensors to be Mounted with Prototype Detectors.

No.	*Species*	*Sensor Range*	*Resolution*	*Instrument Model No.*	*Manufacturer*
1	Oxygen (O_2)	0-25%	0.1% O_2	6C	City Technology
2	Hydrogen sulfide (H_2S)	0-5 ppm	0.1 ppm	TC4A-1A	City Technology
3	Nitric oxide (NO)	0-20 ppm	0.5 ppm	TF3C-1A	City Technology
4	C_1 to C_6 Hydrocarbons (Ethylene) (will be calibrated with ethylene)	0-50 ppm	$\pm$2.5 ppm	SM95-S2 with generalhydrocarbons solid state sensor	International Sensor Technology
5	Residential ionization smoke detector with standard housing	~3.5 to 7 V		83R	First Alert
6	Residential ionization smoke detector without housing or bug screen	~3.5 to 7 V		83R	First Alert
7	SamDetect ™ A multi-sensor fire detector	various	(confidential)	SamDetect B1	RST, DaimlerChrysler

6.0 PROCEDURE AND SAFETY

At the beginning of each day, the daily checklist was completed (Appendix C). Prior to each test, the test area was cleared of all personnel not involved with testing from frames 15 to 29 on the second deck. All designated hatches and doors were closed, and the prescribed ventilation was set. After completion of these tasks, test personnel were positioned in the appropriate locations. When the fuel package was prepared and the safety team in position, data collection and videos were initiated. Following approximately 5 minutes of background data (reduced to 3 minutes after test EWFD_059), either the fire was ignited, the "nuisance activity" initiated or the Calrod energized for the smoldering fire scenarios. During the test, SHADWELL personnel made visual observations, and event data was collected for the duration of the test. After the fire/nuisance activity was complete or all of the compartment's sensors had alarmed, the compartment was ventilated by opening the F-stop at 2-15-1 and WTD 2-29-0 and turning on the E1-15-1 fan. Data collection continued for 10 additional minutes to assess the recovery of the sensors following the event. Once the safety team deemed the test area safe for personnel without breathing protection, the test area was prepared for the next test. This preparation included any cleanup of the test area, equipment setup for the next test, and verification of instruments.

7.0 TEST SUMMARY

This section provides a summary of all the tests conducted. Table 8 presents the pertinent test times, ambient conditions, and general information from this test series. Tables 9 and 10 show the results from the Simplex COTS and residential ionization detectors, showing alarm times, classifications, and sensor readings at alarm for the prototype detectors. In these tables, "DNA" means "did not alarm", "NDT" means "no data taken" for that particular test. Table 11 presents a summary of all tests conducted sorted by source type. Discussion of the results as they apply to the objectives of this test series is presented in Section 8.

8.0 RESULTS AND DISCUSSION

The results from the test series as they apply to the objectives of the test series are discussed in this section. The results and conclusions presented in this report are primarily documentary. Analysis of the PNN alarm algorithm development and performance (Objective 2) will be presented in a separate report.

A broader range of source signature data was produced in this test series (Objective 1), particulary in the area of nuisance and smoldering fire sources. Five new nuisance sources were introduced in this test series, including toasting Pop-Tarts™, spraying of hairspray and deodorant aerosol products, sweeping up a dropped bag of flour to create a dust cloud, steam generation, and cooking oils. Although some increase in signatures was measured, these additional nuisance sources did not always result in alarms from the COTS smoke detectors. Two smoldering fire sources were also added to the test array, utilizing two new types of smoldering cable fires (BSI 6266 and LSTPNW-1½).

The Simplex COTS detectors and the residential ionization detectors were evaluated for their ability to correctly classify each test source as a fire or nuisance. For fire sources, correct classification for all detectors was achieved if the detector went into an alarm state at any time between ignition/initiation of the source and the start of post-test ventilation. For nuisance sources, correct classification for all detectors was achieved if the detector remained out of an alarm state for the time between the initiation of the nuisance source and the start of post-test ventilation. The classification results for the Simplex COTS and residential ionization detectors are shown in Tables 12 and 13.

A revised method for executing real-time detection to maintain a constant sampling and processing interval of 2 seconds (Objective 3) was not successfully completed prior to the test series. However, a solution was obtained shortly after Test Series 2 and will be implemented for the next test series.

Table 8. Times, Conditions, and Comments of Test Scenarios.

Test	Fire type	Brief Description	Loc.	Date	DAQ Start time	Ignition / Initiation time	Ignition / Initiation Time (sec)	Ventilation start time	Vent time (secs after initiation)	Ambient Conditions				Test Comments
										Temperature (°F)	Relative Humidity (%)	Wind Speed (mph)	Wind Direction (degrees)	
038	fire, flaming	Heptane	1	4/27/00	12:31:55	12:37:59	364	12:58:35	1236	70	69	15	140	Prototype 1A ionization detector was changed from #1 to #7 before this test.
039	fire, flaming	Pipe insulation and fuel oil	1	4/27/00	13:51:35	13:57:01	326	14:19:28	1347	71	79	8	148	The 10-minute post-test background data from this test may have been affected by Coast Guard fire testing on the State of Maine test facility (starboard of the ex-USS Shadwell), as ventilation drew smoke from the well deck that was generated by Coast Guard testing.
040	fire, flaming	Flaming oily rag, newspaper, cardboard in sm. Trashcan	1	4/27/00	15:05:45	15:11:12	326	15:33:02	1310	71	83	9	117	
041	Nuisance	Pop-Tarts toasting (8)	2	4/27/00	15:57:25	16:02:40	315	16:10:40	480	71	85	10	129	Second set of 4 pop tarts initiated 265 seconds after initial initiation.
042	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. Trashcan	1	4/28/00	16:29:48	16:34:56	308	17:05:42	1838	71	85	9	126	Variac at 50%
043	fire, flaming	Heptane	1	4/28/00	8:54:49	9:00:09	320	9:27:10	1621	69	81	16	227	
044	fire, flaming	Heptane	3	4/28/00	11:18:45	11:24:34	347	11:47:00	1346	73	56	15	283	New source location (3). 0.84m (2ft-9in.) from 29 BH, 1.27m (4ft-2in.) from Port BH. New TC location 2.74m (9ft) from 29 BH, 2.36m (7ft-9in.) from Port BH.

Table 8. Times, Conditions, and Comments of Test Scenarios (continued)

Test	Fire type	Brief Description	Loc.	Date	DAQ Start time	Ignition / Initiation time	Ignition / Initiation Time (sec)	Ventilation start time	Vent time (secs after initiation)	Ambient Conditions				Test Comments
										Temperature (°F)	Relative Humidity (%)	Wind Speed (mph)	Wind Direction (degrees)	
045	fire, smoldering	Smoldering plastic bag of mixed trash	3	4/28/00	13:17:45	13:22:59	312	14:24:18	3679	77	38	19	290	Variac increased to 65% at 1819 seconds after initiation and to 75% at 3312 seconds after initiation. Flaming occurred at 3591 seconds after initiation.
046	fire, flaming	Flaming bag of trash next to TODCO wallboard	3	5/1/00	10:17:28	10:24:58	450	10:43:14	1098	72	89	12	131	Prototype 2A ion detector was changed from #4 to #5 before this test.
047	Nuisance	Burning popcorn	2	5/1/00	12:35:01	12:40:08	306	12:52:24	736	74	82	9	144	
048	Nuisance	Cutting Steel with acetylene torch	2	5/1/00	13:34:25	13:39:31	317	14:00:12	1241	73	84	10	157	Door from CIC to CSO was open during this test. (QAWTD 2-22-2)
049	Nuisance	Cutting Steel with acetylene torch	2	5/1/00	14:23:12	14:29:00	348	14:48:28	1164	74	85	13	144	Door from CIC to CSO was closed during this test. (QAWTD 2-22-2)
050	fire, flaming	Electrical cable and pipe insulation next to flaming laundry pile	3	5/1/00	15:56:31	16:02:12	341	16:08:00	348	74	86	18	132	
051	fire, smoldering	Long duration smoldering electrical cables	3	5/1/00	16:39:22	16:44:28	306	17:12:38	1690	74	87	16	134	

Table 8. Times, Conditions, and Comments of Test Scenarios (continued)

Test	Fire type	Brief Description	Loc.	Date	DAQ Start time	Ignition / Initiation time	Ignition / Initiation Time (sec)	Ventilation start time	Vent time (secs after initiation)	Ambient Conditions				Test Comments
										Temperature (°F)	Relative Humidity (%)	Wind Speed (mph)	Wind Direction (degrees)	
052	Nuisance	Welding steel plate	2	5/2/00	9:33:00	9:38:17	317	9:57:56	1179	73	99	7	107	Used 14 rods.
053	fire, smoldering	Smoldering bedding	3	5/2/00	10:40:20	10:45:33	313	11:02:30	1017	74	94	11	142	Variac at 65%
054	fire, flaming	Flaming bedding	3	5/2/00	12:11:14	12:16:27	313	12:22:10	343	74	92	16	131	
055	fire, smoldering	Printed wire board (PWB) fire	2	5/2/00	12:46:30	12:51:46	316	13:21:10	1764	74	94	16	144	Power source at 8.5A, 6V. First sign of smoke occurred 531 seconds after initiation.
056	fire, smoldering	Printed wire board (PWB) fire	2	5/2/00	14:10:50	14:18:09	437	14:44:46	1597	74	91	22	144	Fire Curtain installed prior to this test. It covered the entire entrance to the starboard alcove of CSO. First sign of smoke occurred 565 seconds after initiation.
057	fire, smoldering	Printed wire board (PWB) fire	2	5/3/00	16:02:06	16:07:26	320	16:36:50	1164	74	88	21	136	Position of prototypes 1A and 2A switched. First sign of smoke occurred 128 seconds after initiation. Current was lost 394 seconds after initiation. New board was installed and power was turned back on 600 seconds after initial initiation. First sign of smoke with second board occurred 80 seconds after initiation.
058	fire, smoldering	Printed wire board (PWB) fire	2	5/3/00	11:15:22	11:16:30	75	11:37:00	1830	75	87	3	90	Prototypes 1A and 2A put back in original locations. Prototypes 1B and 2B moved to location "A". See figure 2 in report for details. First sign of smoke occurred 85 seconds after initiation.

Table 8. Times, Conditions, and Comments of Test Scenarios (continued)

Test	Fire type	Brief Description	Loc.	Date	DAQ Start time	Ignition / Initiation time	Ignition / Initiation Time (sec)	Ventilation start time	Vent time (secs after initiation)	Ambient Conditions				Test Comments
										Temperature (°F)	Relative Humidity (%)	Wind Speed (mph)	Wind Direction (degrees)	
059	fire, smoldering	Brief (30 sec) wire overheat	3,2	5/3/00	12:30:22	12:35:25	306	12:47:28	723	76	76	12	167	First three wires were at source location 3. Last two wires were ate source location 2. Wire initiation times for the last four wires were 168, 263, 413, and 505 seconds after the first wire initiation.
060	fire, smoldering	BSI 6266 wire test	2	5/3/00	13:08:30	13:11:32	182	13:15:30	238	76	75	11	150	
061	fire, smoldering	BSI 6266 wire test	2	5/3/00	13:33:38	13:26:39	181	13:31:26	287	77	72	15	121	
062	Nuisance	Cooking Oil	2	5/3/00	13:53:42	13:56:45	183	14:23:40	1615	77	70	15	160	Wok set on high. Shortening used in this test.
063	Nuisance	Aerosol deodorants and hairspray	2	5/3/00	14:43:05	14:46:09	185	14:50:00	231	74	73	17	158	
064	Nuisance	Sweeping up a dropped bag of flower	3,2	5/3/00	15:10:25	15:13:27	182	15:27:25	838	77	71	20	197	Radio was keyed before the end of the test, 592 seconds after ventilation was started.
065	Nuisance	Pop-Tarts toasting (8)	2	5/3/00	16:12:12	16:12:13	181	16:20:38	505	78	66	12	168	Eight Pop Tarts were toasted at once, using the highest toaster setting.
066	Nuisance	Normal Toasting (8 slices at a time, 16 total)	2	5/3/00	16:37:08	16:40:09	181	16:48:54	525	78	73	15	164	After the first 8 slices of toast were removed, the second set of 8 slices was put in the toasters at 278 seconds after initial initiation. Power was lost 525 seconds after the initial initiation and the test was terminated at that point.

Table 8. Times, Conditions, and Comments of Test Scenarios (continued)

Test	Fire type	Brief Description	Loc.	Date	DAQ Start time	Ignition / Initiation time	Ignition / Initiation Time (sec)	Ventilation start time	Vent time (secs after initiation)	Ambient Conditions				Test Comments
										Temperature (°F)	Relative Humidity (%)	Wind Speed (mph)	Wind Direction (degrees)	
067	Nuisance	Normal Toasting (8 slices at a time, 16 total)	2	5/4/00	9:10:45	9:13:49	184	9:21:07	438	71	54	19	90	Prototype 1A ionization detector was changed from #7 to #6 before this test. Prototype 1A photoelectric detector was also changed from #1 to #8 before this test. 1A smoke detector outputs were found to be invalid. After the first 8 slices of toast were removed, the second set of 8 slices was put in the toasters at 231 seconds after initial initiation. Data beyond 1430 seconds after initiation should be disregarded.
068	Nuisance	Cigarette smoking	2	5/4/00	10:05:08	10:08:10	182	10:28:10	1200	76	78	8	139	Prototype 1A ion and photo detectors were switched back to #7 and #1 respectively before this test. 15 total cigarettes were smoked.
069	Nuisance	Steel grinding	2	5/4/00	11:38:09	11:41:11	182	11:58:24	1033	NDT	NDT	NDT	NDT	Cardboard was waved to mix the air and grinding particulate (60 seconds) at approximately 550 seconds after initial initiation.
070	fire, flaming	Flaming oily rag, newspaper, cardboard in sm. trashcan	3	5/4/00	12:42:47	12:46:00	193	12:52:56	416	77	82	14	110	

Table 8. Times, Conditions, and Comments of Test Scenarios (continued)

Test	Fire type	Brief Description	Loc.	Date	DAQ Start time	Ignition / Initiation time	Ignition / Initiation Time (sec)	Ventilation start time	Vent time (secs after initiation)	Ambient Conditions				Test Comments
										Temperature (°F)	Relative Humidity (%)	Wind Speed (mph)	Wind Direction (degrees)	
071	fire, smoldering	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	2	5/4/00	13:26:42	13:31:42	300	13:58:03	1581	77	83	19	160	Arc welder was initially set to 250A, 50% power. Increased to 60% at 587 seconds after initial initiation, 70% at 888 seconds, 80% at 1053 seconds, and 100% at 1363 seconds.
072	Nuisance	Cooking Oil	2	5/4/00	14:05:53	14:09:57	244	14:16:10	373	NDT	NDT	NDT	NDT	Portable propane stove used on high for this test. Initially started with 2 teaspoons of vegetable oil. Additional teaspoon added 145 seconds after initiation. Source transitioned from nuisance to fire at approximately 243 seconds after initiation.
073	fire, smoldering	Brief (30 sec) wire overheat	2	5/4/00	14:37:50	14:40:51	181	14:43:50	179	76	88	24	150	
074	fire, smoldering	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	2	5/4/00	15:03:07	15:06:07	180	15:11:37	330	76	90	21	171	Cable broke at 198 seconds after initiation.
075	Nuisance	Steam generation	2	5/4/00	15:30:08	15:33:09	181	15:46:34	805	77	84	15	141	Propane burner and skillet used for this test.
076	Nuisance	Steam generation	2	5/4/00	15:57:06	16:00:06	180	16:03:40	214	76	87	16	140	Skillet was preheated with a torch until it was red hot for this test.

Table 8. Times, Conditions, and Comments of Test Scenarios (continued)

Test	Fire type	Brief Description	Loc.	Date	DAQ Start time	Ignition / Initiation time	Ignition / Initiation Time (sec)	Ventilation start time	Vent time (secs after initiation)	Ambient Conditions: Temperature (°F)	Relative Humidity (%)	Wind Speed (mph)	Wind Direction (degrees)	Test Comments
077	fire, smoldering	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	3	5/4/00	16:16:42	16:19:42	180	16:27:04	442	76	91	16	142	Arc welder at 375A, 100% power.
080	Nuisance	Cooking Oil	2	5/5/00	9:01:50	9:04:50	180	9:10:36	399	71	97	12	97	Propane burner (on high) and skillet used for this test, with 2 teaspoons of vegetable oil. Extra oil added 209 seconds after initiation.
081	Nuisance	Steam generation	2	5/5/00	9:33:42	9:36:49	187	DNV	-	73	92	10	83	Steel pan heated with torch until red-hot. Stopped to reheat pan at 229 seconds after ignition. Did not ventilate and will continue in test 082.
082	Nuisance	Steam generation	2	5/5/00	9:47:30	9:50:44	194	9:54:10	206	NDT	NDT	NDT	NDT	Initiation in this test was 606 seconds after the pan was removed in test 081.
083	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. Trashcan	3	5/5/00	10:20:47	10:23:47	180	10:33:49	602	75	83	11	118	Prototype 2B was moved back to location B for this test. No cardboard was used in the fuel package in this test, and the variac was initially set to 75%.
084	fire, smoldering	Smoldering bedding	3	5/5/00	11:07:31	11:10:32	181	11:53:24	2572	76	80	15	150	Variac initially energized to 60%. Increased to 70% at 2145 seconds after initiation and to 80% at 2402 seconds after initiation.

Table 8. Times, Conditions, and Comments of Test Scenarios (continued)

Test	Fire type	Brief Description	Loc.	Date	DAQ Start time	Ignition / Initiation time	Ignition / Initiation Time (sec)	Ventilation start time	Vent time (secs after initiation)	Ambient Conditions				Test Comments
										Temperature (°F)	Relative Humidity (%)	Wind Speed (mph)	Wind Direction (degrees)	
085	fire, smoldering	Long duration smoldering electrical cables	3	5/5/00	12:50:02	12:53:02	180	11:57:23	261	76	80	14	137	Arc welder was set at 350A. Wrong cable was used in this test. The cable used was either LSTSGU-9 MZ4643/16-03UN or LSTSGU-4 MZ4643/16-02UN
086	fire, smoldering	Long duration smoldering electrical cables	3	5/5/00	13:09:44	13:12:45	181	13:16:36	231	77	82	18	146	Arc welder was set at 375A. Wrong cable was used in this test. The cable used was either LSTSGU-9 MZ4643/16-03UN or LSTSGU-4 MZ4643/16-02UN
087	Nuisance	Cigarette smoking	2	5/5/00	13:34:15	13:37:15	180	13:49:30	735	76	79	18	153	
088	fire, smoldering	Long duration smoldering electrical cables	3	5/5/00	14:01:45	14:04:45	180	14:49:10	2665	76	80	20	151	

Table 9. Summary of Alarm Responses of the Simplex COTS Detectors.

Test	Fire type	Brief Description	COTS Photo (56) Location "A"			COTS Ion (55) Location "A"			COTS Photo (54) Location "B"			COTS Ion (68) Location "B"		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?
038	fire, flaming	Heptane	1016	fire	Y	115	fire	Y	1161	fire	Y	469	fire	Y
039	fire, flaming	Pipe insulation and fuel oil	455	fire	Y	107	fire	Y	782	fire	Y	482	fire	Y
040	fire, flaming	Flaming oily rag, newspaper, cardboard in sm. trashcan	478	fire	Y	92	fire	Y	816	fire	Y	514	fire	Y
041	Nuisance	Pop-Tarts toasting (8)	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y
042	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. Trashcan	DNA	-	N	DNA	-	N	DNA	-	N	DNA	-	N
043	fire, flaming	Heptane	1035	fire	Y	90	fire	Y	DNA	-	N	341	Fire	Y
044	fire, flaming	Heptane	DNA	-	N	66	fire	Y	1188	fire	Y	193	Fire	Y
045	fire, smoldering	Smoldering plastic bag of mixed trash	2451	fire	Y	3621	fire	Y	2431	fire	Y	3638	Fire	Y
046	fire, flaming	Flaming bag of trash next to TODCO wallboard	914	fire	Y	812	fire	Y	974	fire	Y	862	Fire	Y

Table 9. Summary of Alarm Responses of the Simplex COTS Detectors (continued)

Test	Fire type	Brief Description	COTS Photo (56) Location "A"			COTS Ion (55) Location "A"			COTS Photo (54) Location "B"			COTS Ion (68) Location "B"		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?
047	nuisance	Burning popcorn	212	nuisance	N	DNA	-	Y	382	nuisance	N	DNA	-	Y
048	nuisance	Cutting Steel with acetylene torch	DNA	-	Y	120	nuisance	N	DNA	-	Y	135	Nuisance	N
049	nuisance	Cutting Steel with acetylene torch	DNA	-	Y	26	nuisance	N	DNA	-	Y	96	Nuisance	N
050	fire, flaming	Electrical cable and pipe insulation next to flaming laundry pile	116	fire	Y	73	fire	Y	238	fire	Y	132	Fire	Y
051	fire, smoldering	Long duration smoldering electrical cables	1643	fire	Y	1644	fire	Y	1042	fire	Y	DNA	-	N
052	nuisance	Welding steel plate	518	nuisance	N	579	nuisance	N	DNA	-	Y	DNA	-	Y
053	fire, smoldering	Smoldering bedding	537	fire	Y	DNA	-	N	1033	vent	N	DNA	-	N
054	fire, flaming	Flaming bedding	DNA	-	N	42	fire	Y	DNA	-	N	DNA	-	N
055	fire, smoldering	Printed wire board (PWB) fire	856	fire	Y	DNA	-	N	DNA	-	N	DNA	-	N
056	fire, smoldering	Printed wire board (PWB) fire	739	fire	Y	DNA	-	N	DNA	-	N	DNA	-	N
057	fire, smoldering	Printed wire board (PWB) fire	1342	vent	N	DNA	-	N	DNA	-	N	DNA	-	N

Table 9. Summary of Alarm Responses of the Simplex COTS Detectors (continued)

Test	Fire type	Brief Description	COTS Photo (56) Location "A"			COTS Ion (55) Location "A"			COTS Photo (54) Location "B"			COTS Ion (68) Location "B"		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?
058	fire, smoldering	Printed wire board (PWB) fire	430	fire	Y	DNA	-	N	1118	fire	Y	DNA	-	N
059	fire, smoldering	Brief (30 sec) wire overheat	553	fire	Y	DNA	-	N	DNA	-	N	DNA	-	N
060	fire, smoldering	BSI 6266 wire test	93	fire	Y	DNA	-	N	DNA	-	N	DNA	-	N
061	fire, smoldering	BSI 6266 wire test	139	fire	Y	DNA	-	N	DNA	-	N	DNA	-	N
062	nuisance	Cooking Oil	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y
063	nuisance	Aerosol deodorants and hairspray	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y
064	nuisance	Sweeping up a dropped bag of flower	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y
065	nuisance	Pop-Tarts toasting (8)	DNA	-	Y	189	nuisance	N	DNA	-	Y	DNA	-	Y
066	nuisance	Normal Toasting (8 slices at a time, 16 total)	DNA	-	Y	214	nuisance	N	DNA	-	Y	DNA	-	Y
067	nuisance	Normal Toasting (8 slices at a time, 16 total)	DNA	-	Y	231	nuisance	N	DNA	-	Y	DNA	-	Y

Table 9. Summary of Alarm Responses of the Simplex COTS Detectors (continued)

Test	Fire type	Brief Description	COTS Photo (56) Location "A"			COTS Ion (55) Location "A"			COTS Photo (54) Location "B"			COTS Ion (68) Location "B"		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?
068	nuisance	Cigarette smoking	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y
069	nuisance	Steel grinding	DNA	-	Y	939	nuisance	N	DNA	-	Y	DNA	-	Y
070	fire, flaming	Flaming oily rag, newspaper, cardboard in sm. trashcan	248	fire	Y	68	fire	Y	270	fire	Y	109	Fire	Y
071	fire, smoldering	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	DNA	-	N	DNA	-	N	DNA	-	N	DNA	-	N
072	nuisance	Cooking Oil	173	nuisance	N	137	nuisance	N	381	vent	Y	DNA	-	Y
073	fire, smoldering	Brief (30 sec) wire overheat	142	fire	Y	DNA	-	N	DNA	-	N	DNA	-	N
074	fire, smoldering	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)	172	fire	Y	172	fire	Y	257	fire	Y	363	Vent	N
075	nuisance	Steam generation	DNA	-	Y	195	nuisance	N	DNA	-	Y	DNA	-	Y

Table 9. Summary of Alarm Responses of the Simplex COTS Detectors (continued)

Test	Fire type	Brief Description	COTS Photo (56) Location "A"			COTS Ion (55) Location "A"			COTS Photo (54) Location "B"			COTS Ion (68) Location "B"		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?
076	nuisance	Steam generation	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y
077	fire, smoldering	Smoldering electrical cable (LSTPNW-1½, MIL C-24643/52-01UN)	238	fire	Y	DNA	-	N	308	fire	Y	DNA	-	N
080	nuisance	Cooking Oil	279	nuisance	N	232	nuisance	N	DNA	-	Y	DNA	-	Y
081	nuisance	Steam generation	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y
082	nuisance	Steam generation	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y
083	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. Trashcan	519	fire	Y	520	fire	Y	533	fire	Y	543	Fire	Y
084	fire, smoldering	Smoldering bedding	1148	fire	Y	2446	fire	Y	2443	fire	Y	2456	Fire	Y
085	fire, smoldering	Long duration smoldering electrical cables	DNA	-	N	DNA	-	N	DNA	-	N	DNA	-	N
086	fire, smoldering	Long duration smoldering electrical cables	DNA	-	N	DNA	-	N	DNA	-	N	DNA	-	N
087	nuisance	Cigarette smoking	DNA	-	Y	DNA	-	Y	DNA	-	Y	DNA	-	Y

Table 9. Summary of Alarm Responses of the Simplex COTS Detectors (continued)

Test	Fire type	Brief Description	COTS Photo (56) Location "A"			COTS Ion (55) Location "A"			COTS Photo (54) Location "B"			COTS Ion (68) Location "B"		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?
088	fire, smoldering	Long duration smoldering electrical cables	DNA	-	N	DNA	-	N	DNA	-	N	2305	Fire	Y

Table 10. Summary of Alarm Responses of the Residential Ionization Detectors.

Test	Fire type	Brief Description	Residential Ion Chamber without Cover			Residential Ion		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?
038	fire, flaming	Heptane	DNA	-	N	129	Fire	Y
039	fire, flaming	Pipe insulation and fuel oil	DNA	-	N	103	Fire	Y
040	fire, flaming	Flaming oily rag, newspaper, cardboard in sm. trashcan	DNA	-	N	104	Fire	Y
041	nuisance	Pop-Tarts toasting (8)	DNA	-	Y	DNA	-	Y
042	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. Trashcan	DNA	-	N	DNA	-	N
043	fire, flaming	Heptane	DNA	-	N	79	Fire	Y
044	fire, flaming	Heptane	DNA	-	N	323	Fire	Y
045	fire, smoldering	Smoldering plastic bag of mixed trash	DNA	-	N	3672	Fire	Y
046	fire, flaming	Flaming bag of trash next to TODCO wallboard	DNA	-	N	913	Fire	Y
047	nuisance	Burning popcorn	DNA	-	Y	DNA	-	Y
048	nuisance	Cutting Steel with acetylene torch	DNA	-	Y	185	Nuisance	N
049	nuisance	Cutting Steel with acetylene torch	DNA	-	Y	36	Nuisance	N
050	fire, flaming	Electrical cable and pipe insulation next to flaming laundry pile	76	fire	Y	152	Fire	Y
051	fire, smoldering	Long duration smoldering electrical cables	1615	fire	Y	DNA	-	N
052	nuisance	Welding steel plate	285	nuisance	N	1192	Vent	Y
053	fire, smoldering	Smoldering bedding	DNA	-	N	DNA	-	N
054	fire, flaming	Flaming bedding	65	fire	Y	DNA	-	N
055	fire, smoldering	Printed wire board (PWB) fire	DNA	-	N	DNA	-	N

Table 10. Summary of Alarm Responses of the Residential Ionization Detectors. (continued)

Test	Fire type	Brief Description	Residential Ion Chamber Only			Residential Ion		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?
056	fire, smoldering	Printed wire board (PWB) fire	DNA	-	N	DNA	-	N
057	fire, smoldering	Printed wire board (PWB) fire	DNA	-	N	DNA	-	N
058	fire, smoldering	Printed wire board (PWB) fire	DNA	-	N	DNA	-	N
059	fire, smoldering	Brief (30 sec) wire overheat	DNA	-	N	DNA	-	N
060	fire, smoldering	BSI 6266 wire test	DNA	-	N	DNA	-	N
061	fire, smoldering	BSI 6266 wire test	DNA	-	N	DNA	-	N
062	nuisance	Cooking Oil	DNA	-	Y	DNA	-	Y
063	nuisance	Aerosol deodorants and hairspray	DNA	-	Y	DNA	-	Y
064	nuisance	Sweeping up a dropped bag of flower	DNA	-	Y	DNA	-	Y
065	nuisance	Pop-Tarts toasting (8)	202	nuisance	N	275	nuisance	N
066	nuisance	Normal Toasting (8 slices at a time, 16 total)	249	nuisance	N	DNA	-	Y
067	nuisance	Normal Toasting (8 slices at a time, 16 total)	461	vent	Y	DNA	-	Y
068	nuisance	Cigarette smoking	DNA	-	Y	DNA	-	Y
069	nuisance	Steel grinding	605	nuisance	N	934	nuisance	N
070	fire, flaming	Flaming oily rag, newspaper, cardboard in sm. trashcan	32	fire	Y	44	fire	Y
071	fire, smoldering	Smoldering electrical cable (LSTPNW-1½, MIL C-24643/52-01UN)	DNA	-	N	DNA	-	N

Table 10. Summary of Alarm Responses of the Residential Ionization Detectors. (continued)

Test	Fire type	Brief Description	Residential Ion Chamber Only			Residential Ion		
			Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?	Alarm Time (sec after initiation)	Test Phase @ Alarm	Correct Classification?
072	nuisance	Cooking Oil	171	nuisance	N	287	nuisance	N
073	fire, smoldering	Brief (30 sec) wire overheat	DNA	-	N	DNA	-	N
074	fire, smoldering	Smoldering electrical cable (LSTPNW-1½, MIL C-24643/52-01UN)	130	fire	Y	DNA	-	N
075	nuisance	Steam generation	DNA	-	Y	DNA	-	Y
076	nuisance	Steam generation	DNA	-	Y	DNA	-	Y
077	fire, smoldering	Smoldering electrical cable (LSTPNW-1½, MIL C-24643/52-01UN)	DNA	-	N	DNA	-	N
080	nuisance	Cooking Oil	274	nuisance	N	DNA	-	Y
081	nuisance	Steam generation	DNA	-	Y	DNA	-	Y
082	nuisance	Steam generation	DNA	-	Y	DNA	-	Y
083	fire, smoldering	Smoldering oily rag, newspaper, cardboard in sm. Trashcan	479	fire	Y	503	fire	Y
084	fire, smoldering	Smoldering bedding	2432	fire	Y	2456	fire	Y
085	fire, smoldering	Long duration smoldering electrical cables	DNA	-	N	DNA	-	N
086	fire, smoldering	Long duration smoldering electrical cables	DNA	-	N	DNA	-	N
087	nuisance	Cigarette smoking	DNA	-	Y	DNA	-	Y
088	fire, smoldering	Long duration smoldering electrical cables	2285	fire	Y	2299	fire	Y

Table 11. Summary of Tests Conducted.

Test Designation	*Fire/Nuisance Scenario*	*Source Location*	*Description*
Flaming Fire Sources			
EWFD_038	F01	1	Heptane
EWFD_043	F01	1	Heptane
EWFD_044	F01	3	Heptane
EWFD_039	F02	1	Pipe insulation and fuel oil
EWFD_040	F03	1	Flaming Oily rag, newspaper, cardboard in sm. Trashcan
EWFD_070	F03	3	Flaming oily rag, newspaper, cardboard in sm. Trashcan
EWFD_046	F06	3	Flaming bag of trash next to TODCO wallboard
EWFD_050	F07	3	Electrical cable and pipe insulation next to flaming laundry pile
EWFD_054	F10	3	Flaming bedding
Smoldering Fire Sources			
EWFD_042	F04	1	Smoldering Oily rag, newspaper, cardboard in sm. Trashcan
EWFD_083	F04	3	Smoldering Oily rag, newspaper, cardboard in sm. Trashcan
EWFD_045	F05	3	Smoldering plastic bag of mixed trash
EWFD_051	F08	3	Long duration smoldering electrical cables
EWFD_085	F08	3	Long duration smoldering electrical cables (wrong cable)
EWFD_086	F08	3	Long duration smoldering electrical cables (wrong cable again)
EWFD_088	F08	3	Long duration smoldering electrical cables
EWFD_053	F09	3	Smoldering bedding
EWFD_084	F09	3	Smoldering bedding.
EWFD_055	F11	2	Printed wire board (PWB) fire
EWFD_056	F11	2	PWB fire, with fire curtain covering alcove entrance in CSO

Table 11. Summary of Tests Conducted. (continued)

Test Designation	*Fire/Nuisance Scenario*	*Source Location*	*Description*
EWFD_058	F11	2	PWB fire
EWFD_059	F12	3,2	Brief wire overheat
EWFD_073	F12	2	Brief (30 sec) wire overheat
EWFD_060	F13	2	BSI 6266 wire test
EWFD_061	F13	2	BSI 6266 wire test
EWFD_071	F14	2	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)
EWFD_074	F14	2	Smoldering electrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)
EWFD_077	F14	3	Smoldering e lectrical cable (LSTPNW-1½ , MIL C-24643/52-01UN)
Nuisance Sources			
EWFD_041	N01	2	Pop-Tarts™ toasting (8)
EWFD_065	N01	2	Pop-Tarts™ toasting (8)
EWFD_052	N02	2	Welding steel plate
EWFD_048	N03	2	Cutting Steel with acetylene torch
EWFD_049	N03	2	Cutting Steel with acetylene torch
EWFD_047	N04	2	Burning popcorn
EWFD_068	N05	2	Cigarette smoking (15 total)
EWFD_078	N05	2	Cigarette smoking. INVALID TEST – no EWFD data.
EWFD_087	N05	2	Cigarette smoking
EWFD_066	N06	2	Normal Toasting (8 slices at a time, 16 total – lost power near end)
EWFD_067	N06	2	Normal Toasting (8 slices at a time, 16 total)
EWFD_069	N07	2	Steel grinding nuisance
EWFD_063	N08	2	Aerosol deodorants and hairspray
EWFD_064	N09	3→2	Sweeping up a dropped bag of flower (started at location 3 and moved towards location 2)

Table 11. Summary of Tests Conducted. (continued)

Test Designation	*Fire/Nuisance Scenario*	*Source Location*	*Description*
EWFD_075	N10	2	Steam generation (propane stove, cast iron skillet)
EWFD_076	N10	2	Steam generation (skillet preheated with torch – red hot)
EWFD_081	N10	2	Steam Generation (preheated steel pan w/ torch)
EWFD_082	N10	2	Steam generation (continuation of EWFD 081)
EWFD_062	N11	2	Cooking shortening in wok
EWFD_072	N11	2	Cooking Oil (used 100% vegetable oil, cast iron skillet and two-burner portable propane stove)
EWFD_079	N11	2	INVALID TEST – no EWFD data. Cooking oil.
EWFD_080	N11	2	Cooking oil.
Other Tests			
Backgnd_5_2			Extended background test
Radio			Test to determine radio transmission effects on sensors
Calibration1 to Calibration8			Sensor calibration tests

Table 12. Detector Classification Performance.

Sensor	*Fire Detection*	*Nuisance Rejection*	*Total*
Simplex Photo 56 (Location A)	22/29 (75.9%)	16/20 (80.0%)	38/49 (77.6%)
Simplex Ion 55 (Location A)	14/29 (48.3%)	10/20 (50.0%)	24/49 (49.0%)
Simplex Photo 54 (Location B)	14/29 (48.3%)	19/20 (95.0%)	33/49 (67.3%)
Simplex Ion 68 (Location B)	12/29 (41.4%)	18/20 (90.0%)	30/49 (61.2%)
Residential Ion Detector, without cover	8/29 (27.6%)	14/20 (70.0%)	22/49 (44.9%)
Residential Ion Detector	12/29 (41.4%)	15/20 (75.0%)	27/49 (55.1%)

Table 13. Detector Fire Source Classification Performance.

Sensor	*Flaming Fire Detection*	*Smoldering Fire Detection*
COTS Photo 56 ("A" Location)	7/9 (77.8%)	15/20 (75.0%)
COTS Ion 55 ("A" Location)	9/9 (100.0%)	5/20 (25.0%)
COTS Photo 54 ("B" Location)	7/9 (77.8%)	7/20 (35.0%)
COTS Ion 68 ("B" Location)	8/9 (88.9%)	4/20 (20.0%)
Residential Ion Detector, Chamber only	3/9 (33.3%)	5/20 (25.0%)
Residential Ion Detector	8/9 (88.9%)	4/20 (20.0%)

The fourth objective of this test series was to evaluate the performance of the prototype detectors with respect to their spacing relative to the fire. As noted above, the PNN alarm algorithm analysis was still being performed at the time of this report. Therefore, specific conclusions regarding spacing cannot be made. In general, it was observed that many of the sources were of such a small size that COTS detectors at Location B did not reach alarm levels. It was also observed that the incipient size of the sources and the low momentum smoke was significantly affected by overhead obstructions (i.e., beams and ducts). The obstructions retarded smoke flow and further decreased the velocity of the gases. In some tests, such as the smoldering cables, the space was visibly filled with smoke and yet no alarms occurred. This result further illustrates the importance of the smoke entry characteristics of the sensors and detectors. With low momentum, fire gases may not penetrate into the measuring chambers of the sensors. The final performance of achieving very early warning with a multisensor detector may depend as much on the entry characteristics as it does on the alarm algorithm.

Transmission of data to the supervisory systems (Objective 5) was successful in a simulated trial. The Penn State Supervisory group was able to receive data via direct TCP/IP transfer. Problems with file access permissions were encountered when using the shared file method. Therefore, further work on this method will not be performed, especially in light of the success of the TCP/IP method.

9.0 CONCLUSIONS

The Early Warning Fire Detection (EWFD) prototype Series 2 tests were conducted on the ex-USS SHADWELL over the period of April 25-May 5, 2000. Forty-nine tests were conducted, including 9 flaming fire sources, 20 smoldering fire sources, and 20 nuisance sources. The report documents the tests conducted and general results for the COTS smoke detection system. The results of the performance of the EWFD prototype detectors will be presented in a separate report.

A broader range of sources were evaluated in this test series particularly in the area of smoldering fires and nuisance sources. As indicated by the high percent correct classification results, many of the nuisance sources did not produce alarm conditions with the COTS smoke detectors. Overall, the selection of sources tested significantly expands the database for optimizing the PNN alarm algorithmn that is being developed for the multi-sensor early warning fire detector.

During this test series, a successful approach for transmitting real-time detector output to a supervisory control system was evaluated. The best method tested was a direct transfer via TCP/IP. This approach and a revised output format will be further evaluated in Test Series 3.

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APPENDIX A – OUTPUT DATA FORMAT

Early Warning Fire Detector (EWFD) Data Output Format

In order for the supervisory groups to access the data, two proposed access methods were developed. The first was a shared file available over the fiber optic network, and the second was through direct TCP/IP tranfer.

For the shared file method, the EWFD data acquisition system wrote all new data at each time step to a file named "ewfd###.csv", where ### was the current test number. The file was located at the node room computer on the fiber optic network with the IP address 89.0.0.66,in a designated shared folder. The first line of the file contained a comma-delimited header that described each column. The portion of the file that was being written (i.e. the current record) was locked while the writing process occurred, however the remainder of the file was open for reading by the supervisory groups. Each line of data (or record) was 235 characters long, including the 'end of line' character (a carriage return). Each data entry in the line of data had a fixed field width, followed by a comma that separated it from the next field. There was no comma between the last field and the 'end of line' character. The widths of the fields are indicated in Table 1. Note that the 1A,2A,1B, and 2B designations in this table follow the EWFD Prototype designations in the report. When this method was tested, a problem with file access was discovered. Specifically, either the Windows NT operating system, or the LabView software would not allow multiple users to open the file at the same time. Because of this problem, the TCP/IP approach was adopted.

The data was made available via direct TCP/IP transfer. At each timestep, the data was broadcast to a designated TCP/IP port address on the node room computer (IP 89.0.0.66) as a 235 character string that is built in the same method as described above. However, a limitation of this method is that only the current data from the data acquisition system is to the supervisory control system groups.

Table A1 – Descriptions of Fields in the Output File.

Data Field	Field Width	Separating Character Width	Total Width
Military time	8	1	9
Test time	5	1	6
Alarm status 1A	2	1	3
Probability 1A	5	1	6
System Sensor ion 1A	6	1	7
System Sensor photo 1A	6	1	7
Carbon monoxide 1A	6	1	7
Relative humidity 1A	5	1	6
Carbon dioxide 1A	6	1	7
Alarm status 2A	2	1	3
Probability 2A	5	1	6
System Sensor ion 2A	6	1	7
System Sensor photo 2A	6	1	7
Carbon monoxide 2A	6	1	7
Relative humidity 2A	5	1	6
RTD temperature 2A	5	1	6
Alarm status 1B	2	1	3
Probability 1B	5	1	6
System Sensor ion 1B	6	1	7
System Sensor photo 1B	6	1	7
Carbon monoxide 1B	6	1	7
Relative humidity 1B	5	1	6
Carbon dioxide 1B	6	1	7
Alarm status 2B	2	1	3
Probability 2B	5	1	6
System Sensor ion 2B	6	1	7
System Sensor photo 2B	6	1	7
Carbon monoxide 2B	6	1	7
Relative humidity 2B	5	1	6
RTD temperature 2B	5	1	6
Oxygen	4	1	5
Hydrogen sulfide	5	1	6
Nitric oxide	5	1	6
Hydrocarbons	4	1	5
Residential ion (chamber only)	4	1	5
Residential ion	4	1	5
Thermocouple A	5	1	6
Thermocouple B	5	1	6
Thermocouple OH	5	0	5
End of line character	1	0	1
		Total	235

Table A2 provides a more detailed description of each entry, along with an example.

Table A2 – Description of Each Field.

Data Field	Units	Example	Description
Military time	HH:MM:SS	14:23:45	Military time in hours, minutes, and seconds
Test time	seconds	345	Elapsed time into experiment (including background collection)
Alarm status 1A	None	1	1=Alarm, 0=No Alarm, -1=Background collection
Probability 1A	None	0.65	Probability of alarm (range is from 0 to 1, -1 indicates background collection)
System Sensor ion 1A	ΔMIC	10.21	Output from the ionization detector, negative values are possible.
System Sensor photo 1A	%/ft	5.21	Output from the photoelectric detector, negative values are possible
Carbon monoxide 1A	ppm	53.1	Carbon monoxide concentration, negative values are possible
Relative humidity 1A	%	65.8	Relative humitiy from 0-100%
Carbon dioxide 1A	ppm	1380.4	Carbon dioxide concentration
Alarm status 2A	None	-1	1=Alarm, 0=No Alarm, -1=Background collection
Probability 2A	None	-1	Probability of alarm (range is from 0 to 1, -1 indicates background collection)
System Sensor ion 2A	ΔMIC	-0.22	Output from the ionization detector, negative values are possible.
System Sensor photo 2A	%/ft	-0.89	Output from the photoelectric detector, negative values are possible
Carbon monoxide 2A	ppm	-1.23	Carbon monoxide concentration, negative values are possible
Relative humidity 2A	%	65.8	Relative humitiy from 0-100%
RTD temperature 2A	°C	31.21	Temperature as measured from the RTD unit on the prototype
Alarm status 1B	None	0	1=Alarm, 0=No Alarm, -1=Background collection

Table A2 – Description of Each Field (continued)

Data Field	Units	Example	Description
Probability 1B	None	0.95	Probability of alarm (range is from 0 to 1, -1 indicates background collection)
System Sensor ion 1B	ΔMIC	10.21	Output from the ionization detector, negative values are possible.
System Sensor photo 1B	%/ft	5.21	Output from the photoelectric detector, negative values are possible
Carbon monoxide 1B	ppm	53.1	Carbon monoxide concentration, negative values are possible
Relative humidity 1B	%	65.8	Relative humitiy from 0-100%
Carbon dioxide 1B	ppm	1380.4	Carbon dioxide concentration
Alarm status 2B	None	-1	1=Alarm, 0=No Alarm, -1=Background collection
Probability 2B	None	-1	Probability of alarm (range is from 0 to 1, -1 indicates background collection)
System Sensor ion 2B	ΔMIC	-0.22	Output from the ionization detector, negative values are possible.
System Sensor photo 2B	%/ft	-0.89	Output from the photoelectric detector, negative values are possible
Carbon monoxide 2B	ppm	-1.23	Carbon monoxide concentration, negative values are possible
Relative humidity 2B	%	65.8	Relative humitiy from 0-100%
RTD temperature 2B	°C	31.21	Temperature as measured from the RTD unit on the prototype
Oxygen	%	19.9	Oxygen concentration
Hydrogen sulfide	ppm	4.03	Hydrogen sulfide concentration, negative values are possible
Nitric oxide	ppm	12.4	Nitric oxide concentration, negative values are possible
Hydrocarbons	ppm	34.9	General hydrocarbon (ethylene) concentrations
Residential ion (chamber only)	Volts	1.98	Voltage output from a residential ionization detector chamber
Residential ion	Volts	3.56	Voltage output from a residential ionization detector

Table A2 – Description of Each Field (continued)

Data Field	**Units**	**Example**	**Description**
Thermocouple A	°C	25.5	Temperature reading at detector location A
Thermocouple B	°C	34.9	Temperature reading at detector location B
Thermocouple OH	°C	22.8	Temperature reading at the overhead at source location 1

APPENDIX B – SMOKE DETECTOR OUTPUT CORRELATIONS

Four System Sensor ionization and four photoelectric detectors were used in the four EWFD prototypes. System Sensor provided correlations (based on UL 268 smoke box data) to convert the sensor outputs to engineering units. The conversions used are listed in Table B1. The ionization ΔMIC (picoamperes) value was converted to percent obscuration per foot (meter) using a second general correlation from System Sensor data obtained from UL 268 smoke box tests. The correlation from ΔMIC values to percent obscuration per foot (meter) was obtained by using a best-fit curve to multiple data sets obtained during the UL 268 calibration tests of the units. The data is shown in Figure B1 and the correlation equation is:

$$\Delta\left(\%obsc/ft\right) = 0.0000034(\Delta MIC)^4 - 0.0004140(\Delta MIC)^3 + 0.0171968(\Delta MIC)^2 - 0.2070225(\Delta MIC) + 0.0004794$$

As can be seen in Figure B1, the relationship between ΔMIC and %Obsc./ft from unit to unit is quite consistent. It is also observed that the correlation is not linear.

In order to better understand the uncertainties in the smoke measurements, a few examples are presented of detector outputs and UL 268 smoke box results. First, the UL 268 smoke box test represents an arbitrary benchmark of comparison for smoke detectors. The test is designed to expose a detector to a consistent range of gray smoke particulate flowing at a fixed flow rate of 0.17 m/s (35 fpm) under the conditions established for the smoke box design. The smoke is produced by a smoldering cotton wick pre-conditioned and initiated per a standard procedure. The smoke produced in the UL 268 smoke box is measured via a lamp/photocell arrangement and a standardized measuring ionization chamber (MIC). The lamp/photocell yields the percent obscuration smoke measurement and the MIC measures the smoke as it causes a reduction in picoamperes of current across the ionization chamber. The lamp/photocell measurement is more sensitive to smokes characterized by low number density and larger diameters, whereas the MIC is more sensitive to larger number density, small diameter particles. As a result, the MIC (and, thus, ionization detectors) tends to respond more to invisible particles than does the lamp/photocell measurement, which is based on light obscuration.

The differences between the measurements is noted to point out the fact that the relationship between the MIC and lamp/photocell (% obscuration) measurements is highly dependent on the smoke source and conditions (e.g., velocity and time history of smoke) for which it is obtained. In the UL 268 smoke box sensitivity test, the MIC and % obscuration measurements are recorded and compared to a set of minimum and maximum profiles as shown in Figure B2. For the test to be a valid test, the measured data must fall within the minimum and maximum profiles. The measured data from the MIC and lamp/photocell establishes the correlation that was presented in Figure B1. As can be seen by the fairly wide range between the

Table B1. Conversions of System Sensor Detectors Used in the Prototypes

Detector Type	*EWFD Tests*	*Prototype*	*Conversion*
Ionization 6	067	1A	ΔMIC = ΔV * 50
Ionization 7	All except 067	1A	ΔMIC = ΔV * 50
Photoelectric 1	067	1A	%/ft = ΔV * 2.7
Photoelectric 8	All except 067	1A	%/ft = ΔV * 4.0
Ionization 4	038 to 045	2A	ΔMIC = ΔV * 47
Ionization 5	046 to 088	2A	ΔMIC = ΔV * 50
Photoelectric 4	All	2A	%/ft = ΔV * 3.0
Ionization 2	All	1B	ΔMIC = ΔV * 50
Photoelectric 2	All	1B	%/ft = ΔV * 2.5
Ionization 3	All	2B	ΔMIC = ΔV * 50
Photoelectric 3	All	2B	%/ft = ΔV * 2.4

minimum and maximum smoke profiles, it is very possible to establish different correlations between MIC and obscuration values depending on how the source produces smoke within the test box. The potential for varied correlations between the two primary reference measurements is one reason that it is impossible to establish an absolute correlation between different model smoke detectors. This is particularly true if the detectors are measured at different times and using different smoke boxes.

As noted above the relationship between the MIC and obscuration measurements is quite dependent on the smoke source and other test conditions. As an example of potential differences that can exist, Figures B3 and B4 show the acceptable UL 268 test profiles for room-fire smoke exposures used to evaluate smoke detectors. Figure B3 shows the acceptable profiles for MIC and obscuration values for a paper fire and Figure B4 shows the profiles for a smoldering wood fire. As can be seen the correlations between MIC and obscuration values that would be obtained from these tests would vary significantly from one another as well as from the smoke box tests using the smoldering wick.

The examples above have illustrated the variations that exist for what are nominally the standard benchmark measurements for evaluating and calibrating smoke detectors. Basically, the data shows that there is not a single relationship between light obscuration and MIC

measurements; rather, the correlation is dependent on a number of variables, particularly the smoke source. These illustrations also point out the fact that the light obscuration and MIC measurements are quantifying different characteristics of the smoke. In the same manner, this is the reason that photoelectric (a light scattering measurement) and ionization detectors respond differently to different sources. Herein lies another difficulty in establishing robust correlations for ionization detectors; different and not uniquely correlated measurement principals are being used when trying to relate the detector output (i.e., a MIC type value) to a more common (fundamental type) smoke measurement, such as percent obscuration per foot (meter). Although this type of correlation is routinely used for establishing the alarm sensitivity of ionization detectors (e.g., alarm equals 1.2 %Obsc./ft), it must be realized that this value only pertains to the test conditions for which it was established, that is, in the UL 268 smoke box operated at 35 fpm velocity with a smoldering cotton wick conditioned and burned to provide the specified smoke profiles.

It is also important to note that the design of the ionization chamber can result in significantly different outputs for a given source. Therefore, different models of detectors (e.g., as manufactured by System Sensor and Simplex) can yield different ionization chamber outputs with time when exposed to the same source and can also have different sensitivities to varying smoke characteristics. For example, some ionization detectors can be more sensitive to a broader range of particle sizes than other detectors.

Despite initial hopes that the System Sensor detectors used in the EWFD prototypes would be relatively well correlated to the Simplex detectors that were used during the earlier development of PNN training data, the test data of Series 1 and 2 suggests that the ionization detectors in particular, may not be producing equivalent profiles when exposed to like sources. The uncertainties discussed above in establishing fundamental correlations between ionization chamber output and percent obscuration smoke measurements partly explains the difficulty in evaluating the problem. The use of percent obscuration measurement (though used for alarm sensitivity) is not a good universal benchmark for relating different ionization detectors. It is possible to establish a correlation between a Simplex and System Sensor ionization detector by simultaneously evaluating both in a UL 268 smoke box and directly comparing the sensor outputs. However, it is not clear how well this correlation will hold for other fuel sources and test conditions. This approach will be evaluated to determine if the correlations developed provide a more meaningful bridge between the EWFD prototype test series data and that obtained during the previous years in the development of the PNN training set .

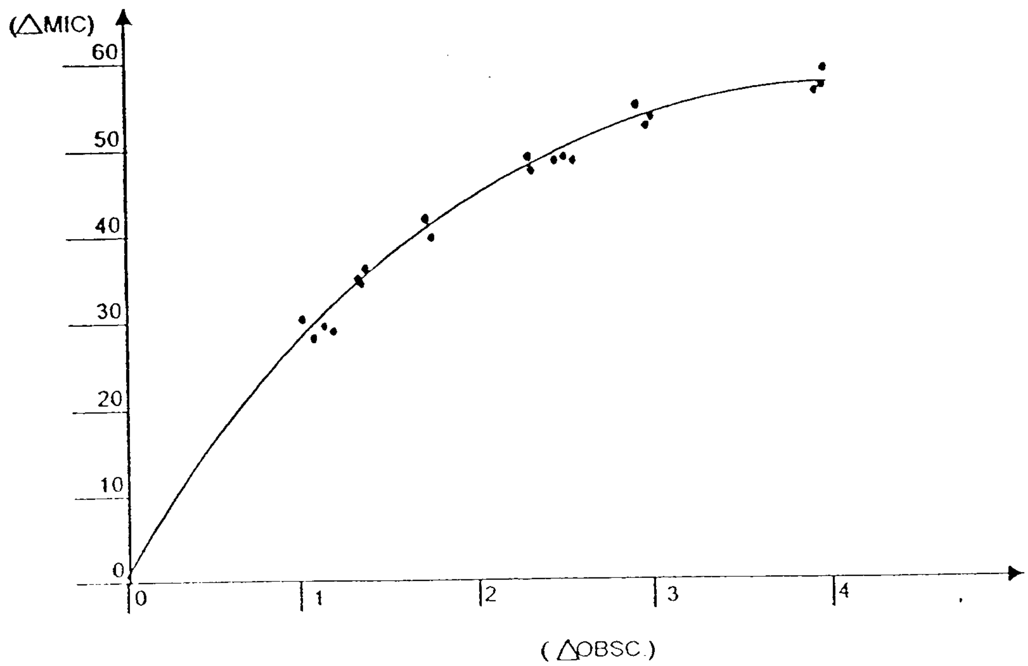


Fig. B1- Correlation data between MIC and change in percent obstruction per foot from UL 268 smoke box tests of the System Sensor dectectors (from System Sensors)

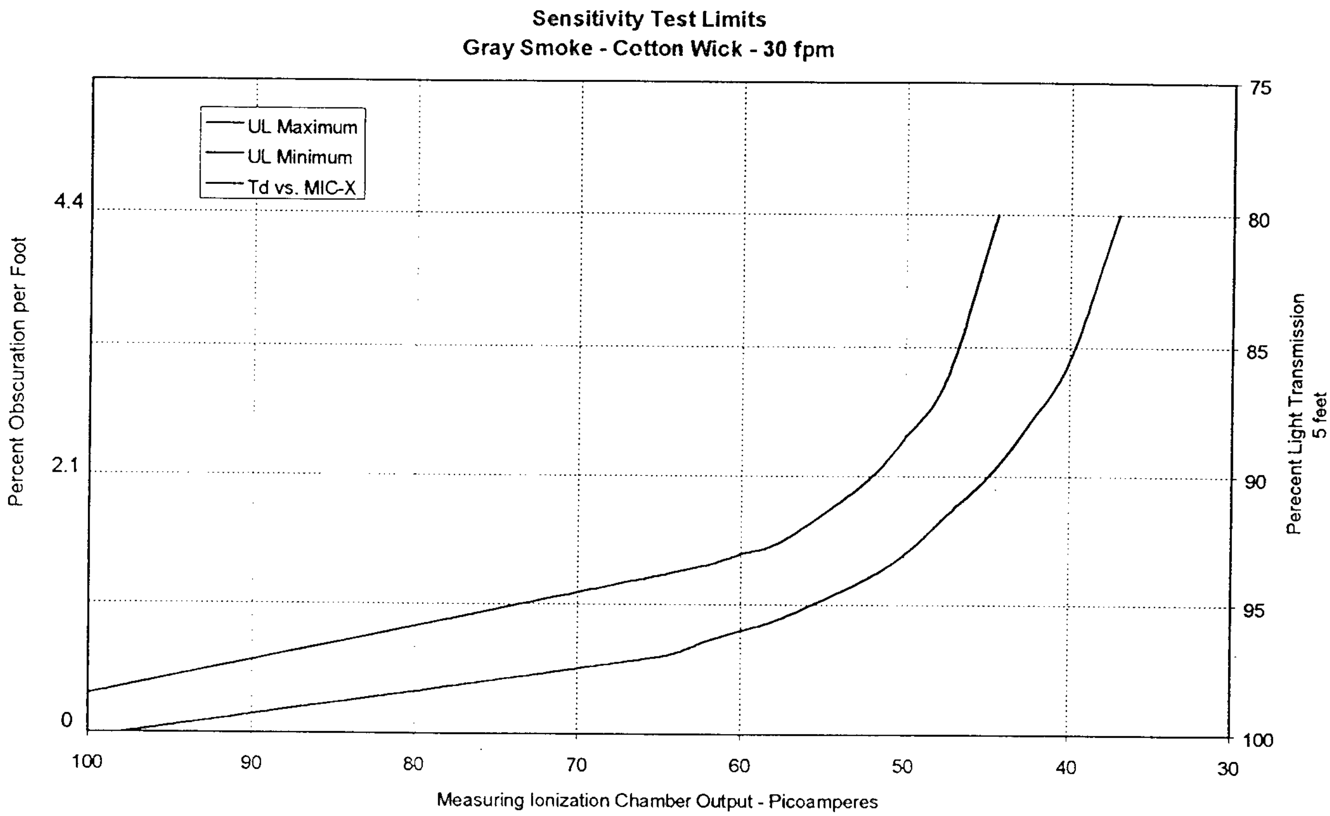


Fig. B2 – The minimum and maximum acceptable profiles for the UL 268 smoke box sensitivity tests.

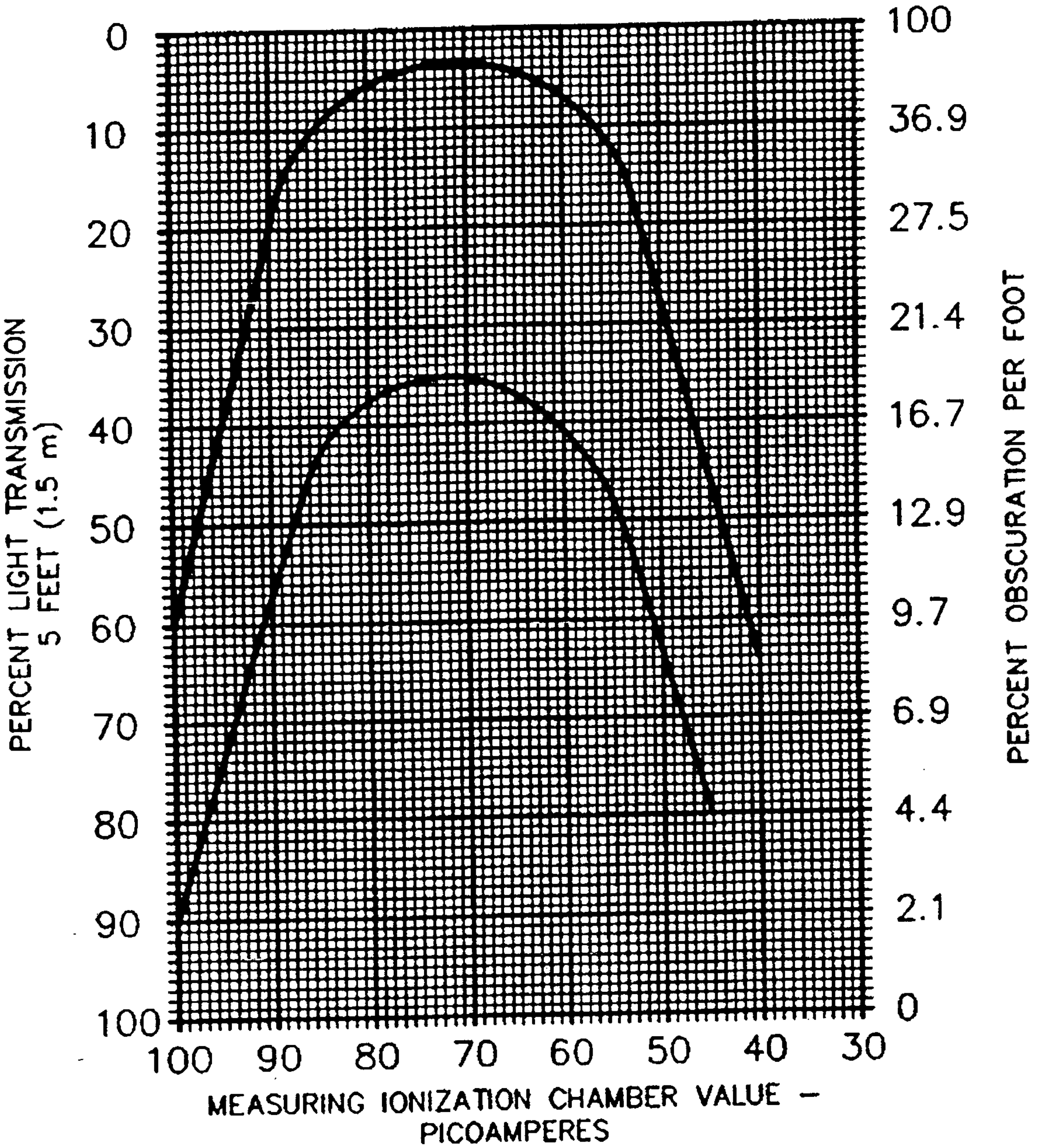


Fig. B3 – The minimum and maximum acceptable profiles for the UL 268 paper fire conducted in a room (from UL 268).

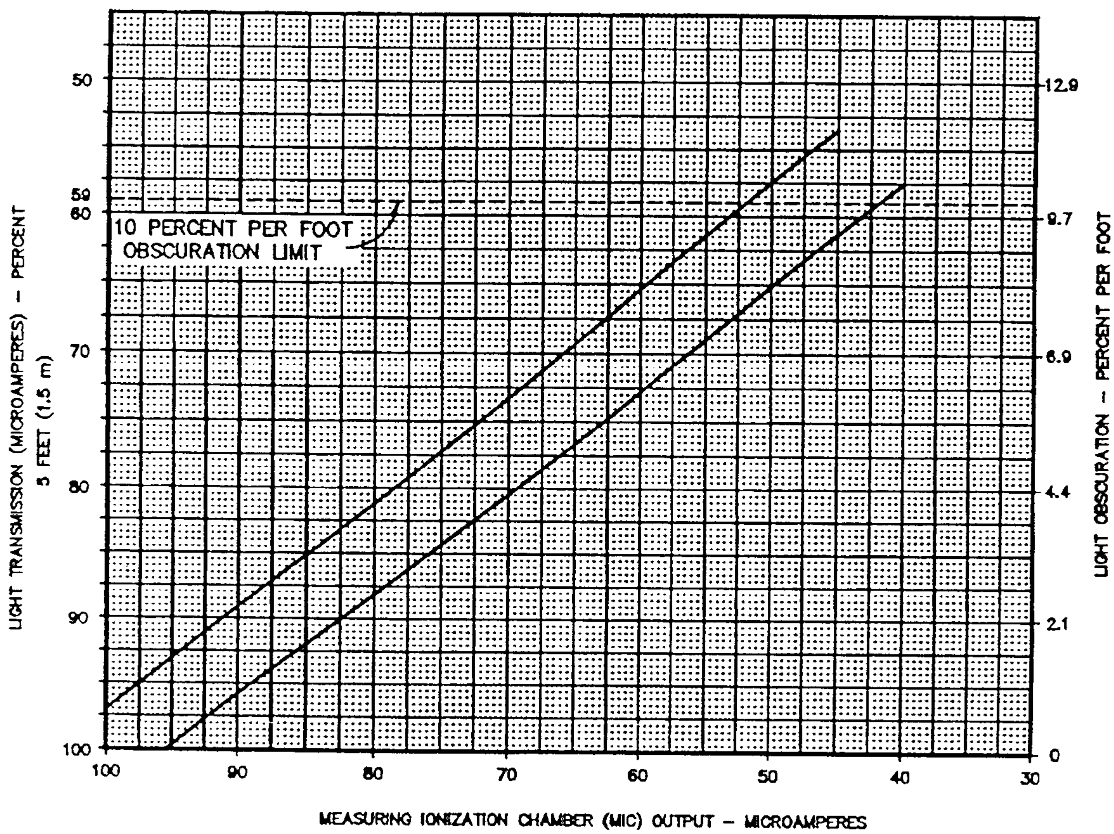


Fig. B4 – The minimum and maximum acceptable profiles for the UL 268 smoldering wood test conducted in a room (from UL 268).

APPENDIX C – DATA ACQUISITION SYSTEM

The data acquisition system consisted of a desktop computer (dual Pentium 200Mhz, 128MB RAM, Windows NT 4.0) with data acquisition card (National Instruments AT-MIO-16F-5), and SCXI 1001 Chassis that housed three SXCI 1100 32-Channel amplifier modules. Attached to each module was a SCXI 1303 Terminal block. The three thermocouples used in this test series were connected to channels 0, 1, and 2 of the terminal block attached to the first amplifier module. The two residential ionization detectors were connected to channels 1 and 2 of the terminal block attached to module three. All remaining sensors were connected to channels 0 to 23 of the terminal block attached to the second amplifier module, as indicated in Table C1.

Table C1. Channel Setup on Second Module of the Data Acquisition System.

Channel	*Sensor*
0	EWFD 1A System Sensor ionization smoke detector (type 1)
1	EWFD 1A System Sensor photoelectric smoke detector (type 1)
2	EWFD 1A carbon monoxide sensor (0-50ppm)
3	EWFD 1A relative humidity transmitter
4	EWFD 1A carbon dioxide sensor (0-5000ppm)
5	EWFD 2A System Sensor ionization smoke detector (type 4)
6	EWFD 2A System Sensor photoelectric smoke detector (type 4)
7	EWFD 2A carbon monoxide sensor (0-100ppm)
8	EWFD 2A relative humidity transmitter
9	EWFD 2A temperature transmitter
10	EWFD 1B System Sensor ionization smoke detector (type 2)
11	EWFD 1B System Sensor photoelectric smoke detector (type 2)
12	EWFD 1B carbon monoxide sensor (0-50ppm)
13	EWFD 1B relative humidity transmitter
14	EWFD 1B carbon dioxide sensor (0-5000ppm)
15	EWFD 2B System Sensor ionization smoke detector (type 3)
16	EWFD 2B System Sensor photoelectric smoke detector (type 3)
17	EWFD 2B carbon monoxide sensor (0-100ppm)
18	EWFD 2B relative humidity transmitter
19	EWFD 2B temperature transmitter
20	Oxygen sensor
21	Hydrogen sulfide sensor
22	Nitric oxide sensor
23	Hydrocarbon sensor

Precision 249Ω resistors were bridged across the terminals of each sensor that provided 4-20mA output, so that the data acquisition could read the results in voltage. Additionally, two voltage dividers were constructed to reduce the output voltage of the residential ionization detectors to the range of the data acquisition system (-5V to +5V). The residential ionization detectors normal output range is ~3.5 to 7 V, which was reduced to ~1.75 to 3.5 V with the voltage dividers. The reduced output voltage is the value recorded in all of the test output files.

The overall setup of the data acquisition system, including the sensors and fiber optic Ethernet connections is shown in Figure C1.

The custom data acquisition software setup required numerous inputs, which are described in Table C2. Note that most of these inputs did not require change from test to test, so they were defaulted to the proper value to benefit the user.

Table C2. Data Acquisition Software Input Setup.

Input	*Default Value (if any)*	*Description*
Device	1	Identifies the data acquisition card in the computer
Cold junction channel	ob0!sc1!md1!mtemp	Identifies the channel from which to read the cold junction compensation temperature (used in thermocouple measurements)
Offset channels	ob0!sc1!md1!calgnd ob0!sc1!md2!calgnd	Identifies the channels from which to read the binary module amplifier offsets (used to reference data acquisition to ground). The thermocouple module must be first, followed by the other module.
TC channels	ob0!sc1!md1!0:2	Channels where thermocouples are connected
Other channels	ob0!sc1!md2!0:25	Channels where all the other sensors are connected
Res Ion Channels	ob0!sc1!md3!1:2	Channels where the residential ionization detectors are located.
TC input limits	0°C to 50°C	Used to set the voltage range from which thermocouple measurements will be made. (does not limit TC readings to this range)
TC type	K	Type of thermocouple used
CJC sensor	Thermistor	Type of sensor used to get the cold junction correction temperature
Voltage input limits	+5V to –5V	Voltage range of the data acquisition system
Alarm probability	(Not defaulted)	Probability threshold for signaling an alarm state
Number of sensors	4	Number of prototype sensors in use
Fire criterion	3	Used in the PNN calculations
Sigma	0.3938[0], 0.4062[1], 0.3938[2], 0.4062[3]	Used in the PNN calculations
Acquisition delay time	2 sec	Amount of time the data acquisition system pauses between each successive reading of data
Background collection time	1 min	Amount of time used for collecting data before an average of the data is taken as background. The PNN also begins to process data after this time.
Scan rate	1000scans/sec	Rate at which the data acquisition card scans each of the data channels
Number of samples to average	50	Each time data is collected from a channel, the data acquisition system gathers this number of samples from the channel at the Scan rate. The average of this sample is taken as the reading from that channel for that timestep.
Output file path	(Not defaulted)	Path and filename of the output file.

Table C2. Data Acquisition Software Input Setup. (continued)

Input	*Default Value (if any)*	*Description*
File header	(Not defaulted)	Text header row to put at the top of the output file (should be comma delimited)
Channel / Type	(various)	Identifies to the software what sensor is associated with each channel. Based on this input, the software converts the raw voltage reading to the correct units in real time.

There are several limitations to the data acquisition setup. The software will not operate properly if these guidelines are not followed:

1) Only three amplifier modules may currently be used. This is due to a limitation in the measurement of binary amplifier offsets for each module. The software has been set up to read only three of these values; one for the thermocouple module, one for the residential ionization detector module, and one for the other sensors module. When these channels are specified in the "offset channels" input, the thermocouple module must be listed first, followed by the "other sensors" module, and finally the residential ionizaiton detector module.

2) The software is currently limited to four prototype detectors. The data channels from the prototypes must always be in the same order as listed in Table C1. If less than four prototypes are used, the extra channels may be deleted, but the order from Table A1 must be preserved. For example, if two prototypes were to be used, channels 0-9 as indicated in Table C1 would have to be used, followed immediately by any additional sensors (oxygen, hydrocarbon, etc.) The order of the extra sensors is unimportant, but they must be after the prototype channels. The reason for these limitations is that several data operations are "hardwired" based on an assumed order of sensors.
3) Each prototype must have five sensors. This is another limitation caused by some "hardwiring" of data operations.

4) The data acquisition card is limited to 200,000 total scans per second. Specifying a scan rate per channel which exceeds this limit for the number of channels being scanned will degrade data acquisition performance.

The processing sequence of the data acquisition was as follows:

1) Acquire background data for the length of time indicated by the user (60 seconds was used in these tests). Average values of each of the sensor readings are taken from this backgound data. During this period, the values read from the System Sensor detectors are voltages. The average voltage from the System Sensor detectors is then

used to calculate the ΔMIC and %/ft outputs for the ionization and photoelectric detectors, respectively. The remainder of the averages for the other sensors are not used.

2) After the background period has passed, the calculations involved with the probabilistic neural network begin to be executed.

3) Once 25 post-background data points have been taken, alarm probability values are calculated.

4) The data collection continues until stopped by the user.

The output file generated by the data acquisition system was a comma-delimited text file. The test time, individual sensor readings, and probability and alarm conditions for each prototype detector were included in the file. The first row contains the header information for each column (specified in the input "file header"), and each row thereafter is the data taken at the next time. Table C3 gives a complete description of the output files generated in this test series.

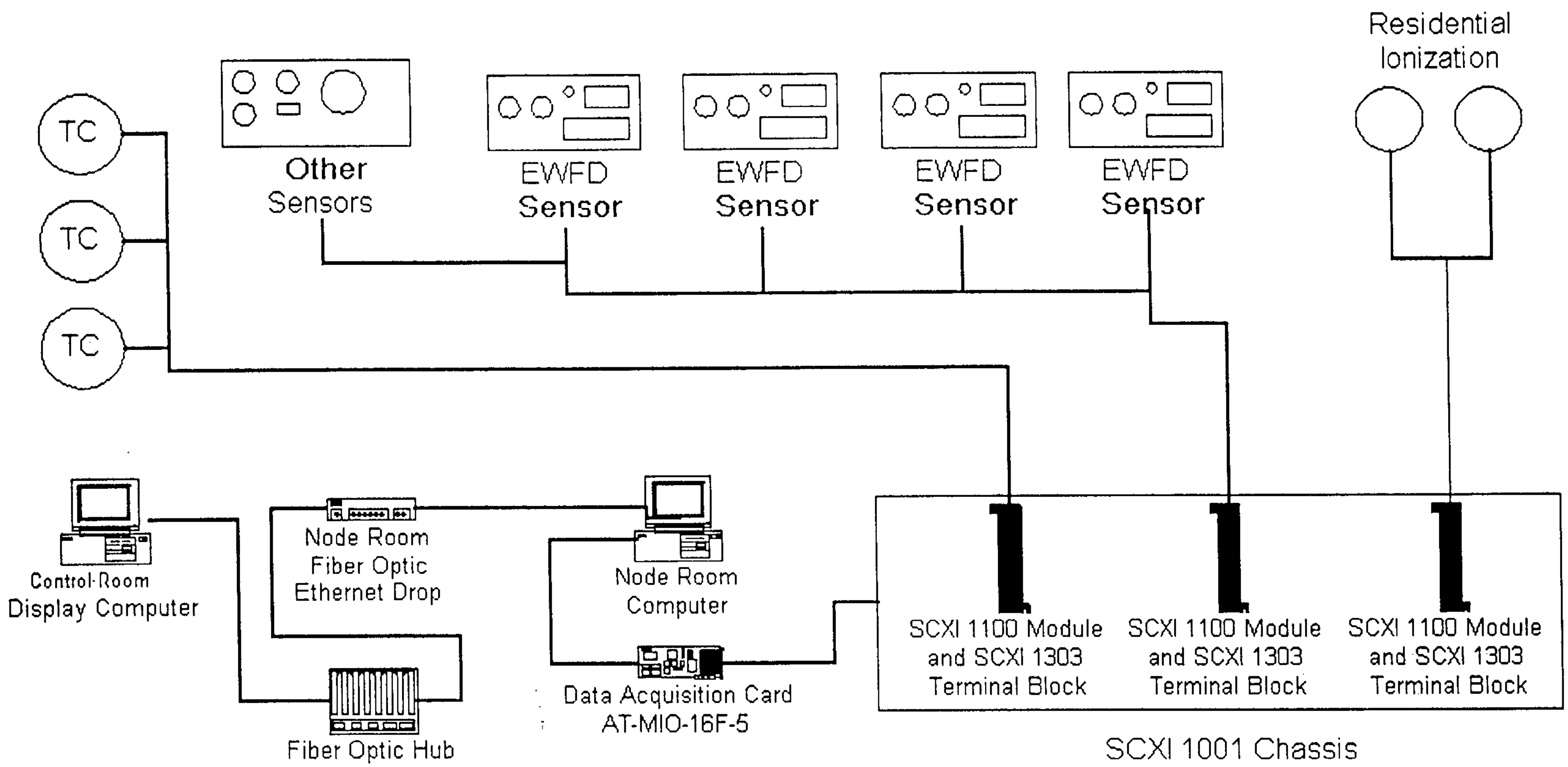
Table C3 – Format of the Output File

Column	*Description*	*Prototype*	*Sensor Range*	*Input Range to Data Acquisition System*	*Units of Values in Ouptut File*
1	Military time	-	-	-	HH:MM:SS
2	Elapsed time	-	-	-	Sec
3	Alarm cndition	1A	-	-	1 = ON, 0 = OFF
4	Probability of alarm	1A	-	-	Dimensionless (0-1)
5	System Sensor ion detector	1A	N/A (See Table 6)	0-5V	ΔMIC
6	System Sensor photo detector	1A	N/A (See Table 6)	0-5V	%/ft
7	Carbon monoxide	1A	0-50ppm	1-5V	ppm
8	Relative humidity	1A	0-100%	0-1V	%
9	Carbon dioxide	1A	0-5000ppm	1-5V	ppm
10	Alarm condition	2A	-	-	1 = ON, 0 = OFF
11	Probability of alarm	2A	-	-	Dimensionless (0-1)
12	System Sensor ion detector	2A	N/A (See Table 6)	0-5V	ΔMIC
13	System Sensor photo detector	2A	N/A (See Table 6)	0-5V	%/ft
14	Carbon monoxide	2A	0-100ppm	1-5V	ppm
15	Relative humidity	2A	0-100%	1-5V	%
16	RTD temperature	2A	-20 to 75°C	1-5V	°C
17	Alarm cndition	1B	-	-	1 = ON, 0 = OFF
18	Probability of alarm	1B	-	-	Dimensionless (0-1)

Table C3- Format of the Output File (continued)

Column	*Description*	*Prototype*	*Sensor Range*	*Input Range to Data Acquisition System*	*Units of Values in Ouptut File*
19	System Sensor ion detector	1B	N/A (See Table 6)	0-5V	ΔMIC
20	System Sensor photo detector	1B	N/A (See Table 6)	0-5V	%/ft
21	Carbon monoxide	1B	0-50ppm	1-5V	ppm
22	Relative humidity	1B	0-100%	0-1V	%
23	Carbon dioxide	1B	0-5000ppm	1-5V	ppm
24	Alarm condition	2B	-	-	1 = ON, 0 = OFF
25	Probability of alarm	2B	-	-	Dimensionless (0-1)
26	System Sensor ion detector	2B	N/A (See Table 6)	0-5V	ΔMIC
27	System Sensor photo detector	2B	N/A (See Table 6)	0-5V	%/ft
28	Carbon monoxide	2B	0-100ppm	1-5V	ppm
29	Relative humidity	2B	0-100%	1-5V	%
30	RTD temperature	2B	-20 to 75°C	1-5V	°C
31	Oxygen	-	0-25%	1-5V	%
32	Hydrogen sulfide	-	0-5ppm	1-5V	ppm
33	Nitric oxide	-	0-20ppm	1-5V	ppm
34	Hydrocarbons	-	0-50ppm	1-5V	ppm
35	Residential ion detector, chamber only	-	typically 3.5-7V	0-5V	Volts (1/2 of actual output)
36	Residential ion detector	-	typically 3.5 - 7V	0-5V	Volts (1/2 of actual output)
37	Thermocouple at Source Location (1 or 3)	-	-200 to 1350°C	MV	°C
38	Thermocouple at A location	-	-200 to 1350°C	MV	°C
39	Thermocouple at B location	-	-200 to 1350°C	MV	°C

Fig C1 - Data Acquisition Setup



APPENDIX D – TEST PROCEDURE

Early Warning Fire Detection Testing

Daily Checklist

Date ____________

VIDEO/AUDIO SYSTEM

_____ Video cameras on
_____ Video display monitors on
_____ Video cassette recorders on, tapes loaded, counters reset
_____ Date/Time generators on, adjust dates or times as necessary

INSTRUMENTATION

_____ Data acquisition systems on
_____ Synchronize computer clock with date/time generators
_____ Data collection program loaded and running

MECHANICAL SYSTEMS

_____ Main fire pumps on
_____ Backup fire pump checked

SAFETY SYSTEMS

_____ Protective clothing in well
_____ OBAs on hand in well
_____ Backup handlines flowed and positioned
_____ PKP extinguisher staged
_____ Ignition torches staged
_____ Two boats available and ready
_____ Coast Guard notified

TEST DAY CONCLUSION

_____ Backup data files to zip disk and set data acquisition for overnight data collection
_____ Video cameras, monitors, and recorders off
_____ Control room power supplies off
_____ Clean and recalibrate ODMs as needed
_____ Secure suppression system water supply

Early Warning Fire Detection Testing

Test Sheet (page ½)

Test Name: EWFD0 ______________ Date:

Description: ____

Ambient Conditions:

Temperature:______(F)   Rel. Humidity:______(%)

Wind Speed:______(mph)   Wind Direction:________(degrees)

- ________ Test area photographed
- ________ Make announcement: "Attention all personnel, fire testing is in progress. All personnel must clear Frames 15 to 29 on the main, second and third decks."
- ________ Closure plan in effect. For CIC fires, TPES & TPSS on. For Ops Office fires, TPES only
- ________ Sound Powered Phone check
  - ___ Safety officer 1
  - ___ Safety officer 2
- ________ Test compartment evacuated (except for fueling personnel)
- ________ Fire main charged
- ________ Sink times, Start data acquisition, Reset COTS
- ________ Start videos
- ________ Initiate source
- ________ Fire ignition (if applicable)
- ________ Test called away
- ________ Source terminated
- ________ Stop video recorders
- ________ Collect 10 minutes of post fire data and background data between tests

Post Test Turnaround

- ________ Commence post fire shutdown as directed
- ________ Safety team open doors/hatches to vent test area completely
- ________ Monitor temperature and sensor data to determine return to baseline conditions

Early Warning Fire Detection Testing

Test Sheet (page 2/2)

Test Name: EWFD0 Date:

NOTES:

Time	Comment